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Using passive track stations to determine the movement and activity of mid-sized mammalian predators and white-tailed deer in northern Iowa

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Using passive track stations to determine the movement and activity of mid-sized mammalian predators and white-tailed deer in northern Iowa

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Signatures have been redacted for privacy

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CHAPTER 1: GENERAL INTRODUCTION AND LITERATURE REVIEW

Introduction

Agricultural practices in Iowa, the Midwest and across the northern Great Plains have decreased the extent of natural grasslands and increased landscape fragmentation (Ratti and Scott 1991, Reynolds 2000, Ryan 2000). Three major effects of habitat loss and fragmentation are decreased patch size, increased habitat edge (Laurance and Yensen 1991) and increased isolation (Fahrig 1997). The detrimental effects of habitat loss on wildlife populations are much greater than effects of fragmentation alone (Fahrig 1997). However, after habitat is lost, the configuration of remaining habitat becomes very important. It is therefore important to understand the movement and activity patterns of wildlife species (Ims 1995) in order to reduce the detrimental effects of fragmentation on populations through landscape management.

Changes in landscape composition and configuration have led to changes in the number, movement and behavior patterns of many wildlife species including generalist predators (Andren et al. 1985, Dijak and Thompson 2000, Reynolds 2000), such as the red fox, (*Vulpes vulpes*), raccoon, (*Procyon lotor*), and striped skunk, (*Mephitis mephitis*) as well as white-tailed deer, (*Odocoileus virginianus*; Sparrowe and Springer 1970, Zagata 1972, Nixon et al. 1991, Roseberry and Woolf 1998, Vercauteren and Hygnstrom 1998). However, species differ in life history and may be influenced differently not only by habitat composition, but also by patch configuration and shape (Wilcove 1985). For example, juxtaposition of patches may be important if patches are smaller than the home range of a species or if patches provide different life requisites. Conversely, animals may move more and in different patterns when fragmentation scatters habitat patches (Ims 1995). In addition to adding complexity to landscape configuration, strip habitat such as road ditches, streams and waterways (Heske 1995) and fence lines (Pedlar et al. 1997) may act as corridors between larger habitat patches (Ims 1995). Finally, the characteristics of edges of patches, including their shape, may also influence the behavior of wildlife. Corners such as concave edges have been predicted to funnel activity into a patch (Ims 1995) with convex corners acting similarly as points of exit or entry into a patch.

Recently, interest in the behavior of mid-sized carnivores has risen because they are the major cause of mortality on duck (Greenwood et al. 1987, Klett et al. 1988, Johnson et al. 1989, Sargeant and Raveling 1992, Sargeant et al. 1993, Pasitschniak-Arts and Messier 1995, Pedlar et al. 1997), pheasant (Clark et al. 1999), and other ground-nesting bird (Gates and Gysel 1978, Andren et al. 1985, Wilcove 1985, Johnson and Temple 1990, Burger et al. 1994, Andren 1995) nests in Iowa and elsewhere in the northern Great Plains. The increased damage to agricultural crops (Conover and Decker 1991, Conover 1994) and an increase in the number of deer-vehicle accidents (Hubbard et al. 2000) have resulted in a similar interest in the movement and activity of white-tailed deer.

Once habitat is lost the configuration and management of the remaining patches in agricultural landscapes becomes important for the conservation and management of predators, nesting birds and deer. Understanding how wildlife use different landscape configurations could help managers choose among land use policies that would reduce the influence of generalist predators on nesting birds or the impact of white-tailed deer on cropland and vehicle accidents.

My research took place from May through mid-July during 1999 and 2000 in the Prairie Pothole Region in Hancock and Winnebago Counties in northcentral Iowa. This time period approximately coincided with mallard (*Anas platyrhynchus*) nesting in the area. Land use is primarily agriculture, with over 75% (Clark et al. *in press*) of land cover in row cropland (corn and soybeans). Additional agricultural land uses include pastureland and hayland. The remaining perennial grassland, woodland and wetland habitats existed in a variety of large blocks, small patches and narrow strips of cover mostly on Waterfowl Production Areas (WPA), Wildlife Management Areas (WMA) and Conservation Reserve Program (CRP) lands.

The objectives of my research were a) to identify important landscape composition and configuration variables influencing the activity of predators and deer, b) to build and select models for predicting predator and deer activity given landscape variables, c) to provide evidence that the predator models have explanatory value in understanding duck nesting success and d) to examine the effect edge shape has on movement direction relative to a patch of grassland habitat by predators and white-tailed deer.

Thesis Organization

This thesis consists of two papers written with the intent for submission to separate journals for publication. Chapter 2, to be submitted to the *Journal of Wildlife Management*, examines movement direction and activity of several mid-sized predators in relation to landscape composition and configuration variables. Chapter 3, to be submitted to the *Journal of Mammalogy*, also examines movement direction and activity in relation to landscape composition and configuration variables, but its focus is on white-tailed deer. Each chapter was written by Aaron K. Kuehl and edited by Dr. W. R. Clark. Following the two papers is Chapter 4 on the general conclusions of the study. Literature cited in Chapter 1 and 4 is listed at the end of the thesis.

CHAPTER 2: PREDATOR ACTIVITY AND MOVEMENT DIRECTION IN RELATION TO LANDSCAPE VARIABLES IN NORTHCENTRAL IOWA

A paper to be submitted to the Journal of Wildlife Management

Aaron K. Kuehl

Abstract

Interest in behavior, activity and movement direction of mid-sized carnivores has risen because they are the major cause of mortality on duck, pheasant and other ground-nesting bird nests in Iowa and elsewhere in the northern Great Plains. By understanding how predators use various landscape features, we can better understand predation risks on nesting birds. I estimated activity and movement direction of striped skunk (*Mephitis mephitis*; hereafter, skunk), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*; hereafter, fox) and all predators combined as a function of landscape variables using un-baited (passive) track stations along the edges of blocks of grassland (Block Edge) and at various distances away from blocks of grassland (Isolated) in northcentral Iowa. Specific landscape variables within a 500-m radius around track station locations were quantified using aerial imagery and a geographic information system for inclusion as predictor variables in the general models for isolated and block edge sample units. Logistic regression with repeated measures and Akaike weights were used to model the influence of landscape composition and configuration variables on predator activity. On isolated sample units skunk activity was inversely influenced by the natural logarithm of the distance (m) to grassland block and positively influenced by the number of farms

within the 500 m buffer, whereas raccoon activity was inversely influenced by the natural logarithm of the distance (m) to woody cover. Area of pastureland (ha) and the natural logarithm of the distance (m) to the nearest farmstead each had a positive influence on fox activity, whereas length of strip habitat (100-m units) was inversely related to fox activity at isolated sample unit locations. When all predator activity at isolated sample units was assessed, their activity was negatively influenced by the natural logarithm of the distance to grassland block and length of strip habitat in the 500-m buffer area. Raccoon and fox activity along the edges of blocks of grassland could not be confidently predicted using the selected landscape variables. The number of wetlands positively influenced skunk activity and overall predator activity was negatively related to the natural logarithm of the distance to woodland, area of woodland (ha), area of pastureland (ha) and edge density of grassland habitat for sample units located along the edge of blocks of grassland. Estimated 2-day activity at duck nests located near (< 500-m) blocks of grassland habitat for skunk ($P = 0.0042$), raccoon ($P = 0.003$), fox ($P = 0.18$) and all predators combined ($P = 0.0074$) was higher than the estimated activity at more isolated (> 500-m) locations. Two-day estimated mortality of a sub-sample of real duck nests was significantly higher for nests that were near ($\overline{m}_{2d} = 0.2027$) blocks of grassland than for more isolated ($\overline{m}_{2d} = 0.0605$) nest locations ($P = 0.0317$). Two-day estimated mortality rates and estimated probability of predator presence at real duck nests were not different on near or far nest locations. More than 74% of predator movement along convex and 80% along concave edges was perpendicular to the grassland - row cropland interface, whereas perpendicular movement accounted for less than 15 % along straight edges (road ditch, drainage ditch, straight block edge) depending on species. Predator activity models such as presented here could be used to predict predator risk and relative nest success of ground nesting birds such as pheasants and waterfowl and choose alternate landscape configurations that could be used to mitigate detrimental effects on nest success by mammalian predators.

Introduction

Agricultural practices in Iowa, the Midwest and across the northern Great Plains have decreased the extent of natural grasslands and increased landscape fragmentation (Ratti and Scott 1991, Reynolds 2000, Ryan 2000). Three major effects of habitat loss and fragmentation are decreased patch size, increased habitat edge (Laurance and Yensen 1991) and increased isolation (Fahrig 1997). In northern Iowa, more than 75% of land use is row crop agriculture (Clark et al. *in press*) and the remaining perennial grassland, woodland and wetland habitats exist in a variety of large blocks, small patches and narrow strips of habitat. Changes in landscape composition and configuration have led to changes in the number, movement and behavior patterns of generalist predators (Andren et al. 1985, Dijak and Thompson 2000, Reynolds 2000), such as the red fox, raccoon and striped skunk. These mid-sized predators are thought to forage and travel along the edges of grassland habitat (Andren 1995, Dijak and Thompson 2000) attracted by the increased diversity of prey (Andren et al. 1985) and cover that edges provide.

Previous studies have identified various landscape composition variables such as farms (Lariviere and Messier 1998), woodland (Pedlar et al. 1997, Dijak and Thompson 2000), grassland (Greenwood et al. 1999, Clark et al. 1999, Phillips et al. *in review*) wetland (Greenwood et al. 1999, Phillips et al. *in review*) and pastureland (Sargeant 1972, Pedlar et al. 1997, Phillips et al. *in review*) that may influence activity of these generalist predators. However, each species differs somewhat in life history so they may be influenced differently not only by habitat composition, but also by patch configuration and shape (Wilcove 1985). Juxtaposition of patches may be important if patches are smaller than the home range of a species or if patches provide different life requisites. Conversely, animals may move more and in different patterns when fragmentation scatters habitat patches (Ims 1995). In addition to adding complexity to the landscape configuration, strip habitat such as road ditches, streams and waterways (Heske 1995) and fence lines (Pedlar et al. 1997) may act as corridors between larger habitat patches (Ims 1995). Finally, the characteristics of edges of patches, including the shape, may influence predator behavior. Researchers observing predator tracks have recognized that coyotes and badgers often bisect block edges during travel, whereas foxes, raccoons and skunks spend more time along the edges of blocks of grassland and their movements often parallel the grassland - row cropland edge (M. A. Sovada, Northern Prairie Wildlife Research Center, personal communication). Corners such as concave edges have been predicted to funnel activity into a patch (Ims 1995) with convex corners acting similarly as points of exit or entry into a patch.

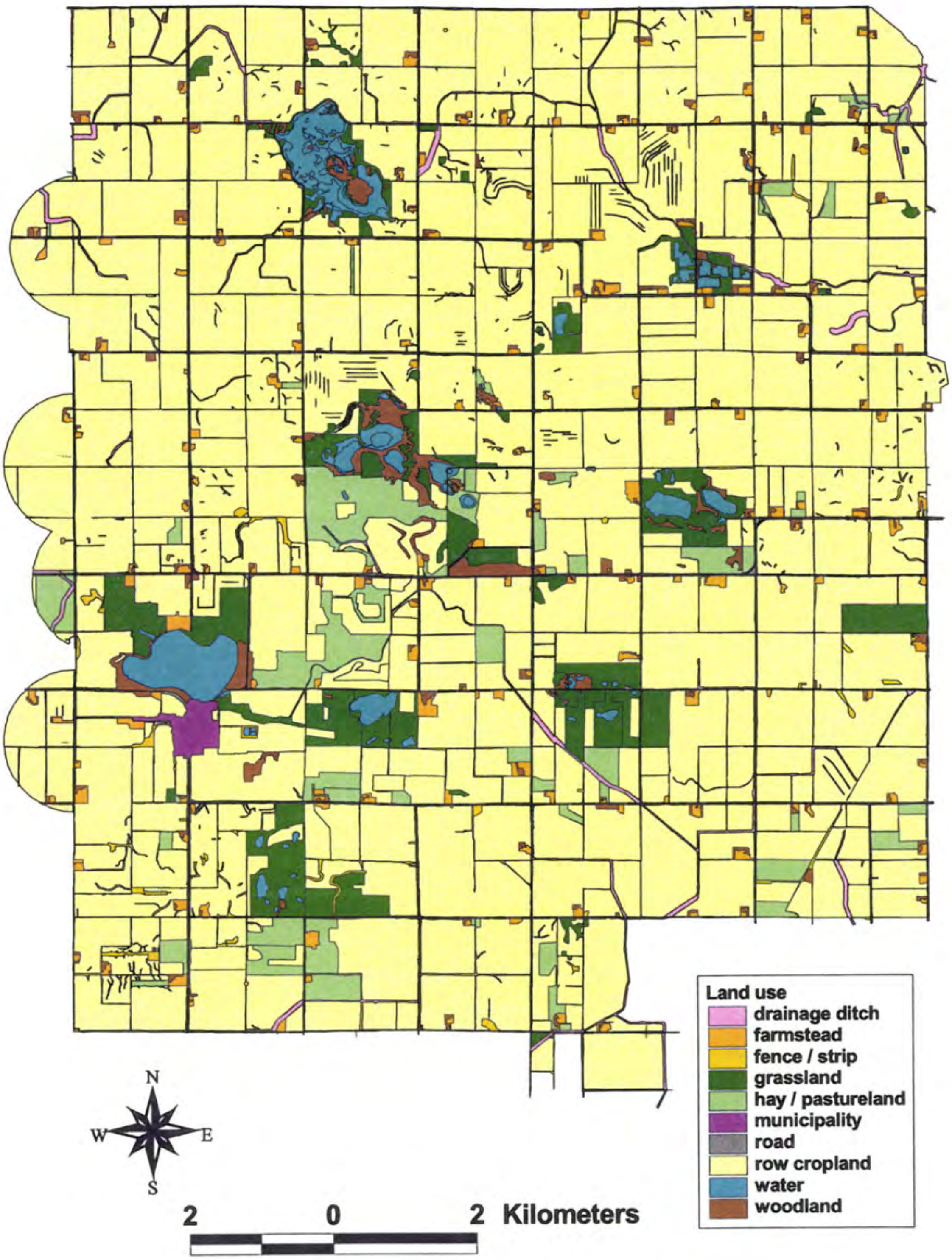
There has been much study on how fragmented landscapes affect nest success and predation of ground nesting birds (Gates and Gysel 1978, Andren et al. 1985, Wilcove 1985, Yahner and Scott 1988, Johnson and Temple 1990, Burger et al. 1994, Paton 1994, Andren 1995, Clark et al. 1999). Although evidence of predator activity is frequently inferred from these studies, few have directly quantified the influence of landscape composition and configuration on predator movement direction and activity (Phillips et al. *in review*). Recently, interest in behavior of mid-sized carnivores has risen because they are the major cause of mortality on duck (Greenwood et al. 1987, Klett et al. 1988, Johnson et al. 1989, Sargeant and Raveling 1992, Sargeant et al. 1993, Pasitschniak-Arts and Messier 1995, Pedlar et al. 1997), pheasant (Clark et al. 1999), and other ground-nesting bird (Gates and Gysel 1978, Andren et al. 1985, Wilcove 1985, Johnson and Temple 1990, Burger et al. 1994, Andren 1995) nests in Iowa and elsewhere in the northern Great Plains.

Once habitat is lost, the configuration and management of the remaining patches of habitat in agricultural landscapes becomes important for the conservation and management of predators and nesting birds alike. I wanted 1) to assess the activity and movement direction of 3 mid-sized predators (skunk, raccoon, and fox) individually and in aggregate and 2) to determine how landscape composition and configuration might be quantitatively related to predator activity and movements. My approach was a) to determine the most important landscape variables influencing the level of predator activity using tracking stations, b) to build and select models for predicting predator activity given landscape variables, c) to provide evidence that the models have explanatory value in understanding duck nesting success and d) to examine the effect edge shape has on predator movement direction relative to a patch of grassland habitat.

Study Area

My research took place between early May and mid-July during 1999 and 2000 within the Eagle Lake Wetland Complex, a project area of the North American Wetland Conservation Act, located in the Iowa Prairie Pothole Region in Hancock and Winnebago counties in northcentral Iowa (Fig. 1). The 127 km^2 study area contains a complex of Wildlife Management Areas (WMA), Waterfowl Production Areas (WPA), Conservation Reserve Program (CRP) lands, and agricultural fields. The Iowa Department of Natural Resources (IDNR) manages nearly 700 ha of upland and 800 ha of wetlands in the study area including the lands owned by the U. S. Fish and Wildlife Service (USFWS).

Figure 1. Habitat classification for the predator study area in Hancock and Winnebago Counties in northern Iowa during the summers of 1999 and 2000.


Land use
drainage ditch
farmstead
fence / strip
grassland
hay / pastureland
municipality
road
row cropland
water
woodland
N
S
W
E
2
0
2 Kilometers

Methods

Predator Activity

Presence of predator tracks identified to species was used to determine predator activity at sample units. I modified the track survey technique used by Sargeant et al. (1993) and Sovada et al. (1995) so that I could randomly distribute sample units in specific locations across the landscape. Sample units were located along the grassland - row cropland interface of road ditches, drainage ditches, sides of blocks of grassland, convex corners of blocks of grassland, and concave corners of blocks of grassland and selected from units within 3 strata.

A sample unit consisted of two sub-units, one placed in the first few rows of row cropland adjacent to the grassland edge and the other was placed 2 m into the grassland habitat. Each sub-unit consisted of three 1-m^2 track stations separated by 3 m with sub-units parallel to the grassland - row cropland interface. The multiple track stations allowed a larger tracking area to be sampled with less disturbance to the habitat, and enabled me to better assess movement direction of predators.

Each station consisted of finely raked soil with a 3.5 cm white disk placed at its center. The sharp contrast between the disk and soil acted as a novel stimulus (Animal and Plant Health Inspection Service 1998) to attract the attention of passing predators to the center of the track station where they may leave a more detectable track without rewarding or conditioning predators to search the area. These un-baited or "passive" track stations better identify true predator activity because predators are not attracted to the sample unit as they are in baited studies. When soil conditions were poor, mineral oil was applied to moisten the soil to improve track registration (M. A. Sovada, Northern Prairie Wildlife Research Center, personal communication). A numerical rating (0-5) of track station condition (Table 1) was recorded to control for differences in the ability to detect and identify predator tracks. Tracks with a rating < 2 were excluded from the analyses.

Sample units were checked after 2 nights of exposure. Similar studies using baited track stations used 1 (Heske 1995, Marini et al. 1995, Winter 2000), 2 (Dijak and Thompson 2000), and week long (Pedlar et al. 1997) exposure periods. I selected 2 exposure nights as a compromise between opportunity for predator response and reduction of weather related disturbances.

Table 1. Rating system used to control for differences in track detectability.

Rating	Description
0	Track station destroyed by plowing or flooding.
1	Soil dry and hard without dust. No chance of track.
2	Soil dry and firm. Thin layer of dust. Track detectable.
3	Soil dry, but soft. Track identifiable.
4	Soil moist and soft. Tracks easily identified.
5	Soil wet and muddy. Tracks well defined and easily identified.

Habitat and Landscape Variables

Land cover data were recorded from low altitude aerial photography for the entire study area and outside the core area where needed to assess landscape variables. Photographs were digitized and georeferenced and ArcInfo / ArcView Geographical Information System (GIS) software was used to map and quantify landscape characteristics. Habitat was classified into one of nine cover types 1) row cropland, 2) strip grassland (terrace, fence line), 3) drainage ditch, 4) grassland block (WMA, CRP, WPA), 5) hayland and pastureland, 6) water, 7) woodland (including shelterbelts surrounding farmsteads), 8) roads and 9) farmsteads that reflected my interest in the influence of landscape variables on predator activity. Classifications were verified by ground observations.

Relating Predator Activity to Landscape Variables

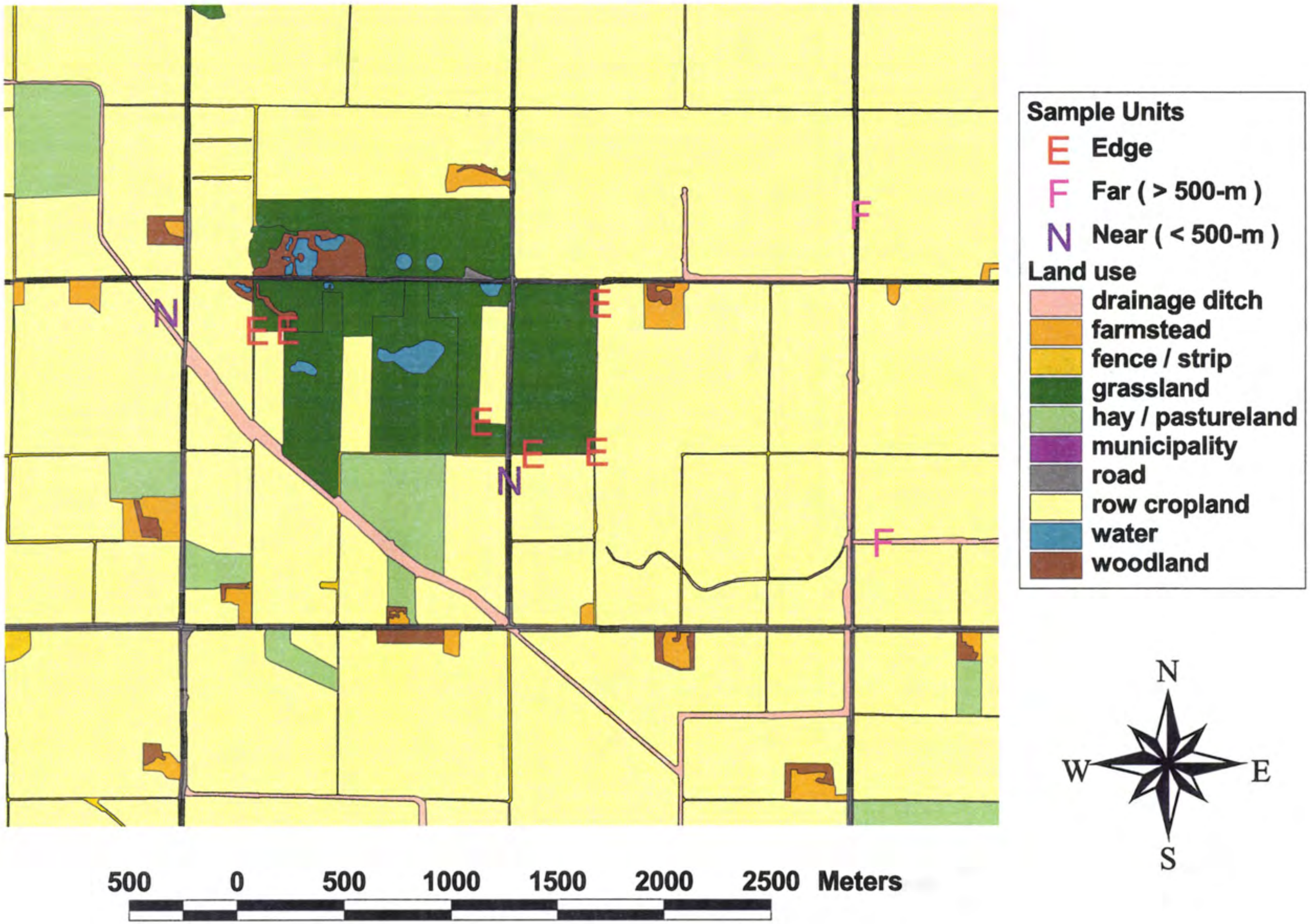
One of my primary interests was the influence that distance away from the nearest block of grassland may have on predator activity. Sample units were selected randomly from 3 strata (Edge, Near and Far) which reflected my interest in isolation (distance to nearest block of grassland). Edge sample units were allocated among sides (n = 13), convex corners (n = 11) and concave corners (n = 13) of blocks of grassland. Near sample units were selected from all the possible 9-m sections of gravel road ditch (n = 10) and drainage ditch (n = 5) that were < 500-m from a block of grassland. Far sample units were selected from all the possible 9-m sections of gravel road ditch (n = 12) and drainage ditch (n = 6) that were

> 500-m from a block of grassland (Fig. 2). Predator activity along the edges of blocks of grassland (Edge) and predator activity away from the edges of blocks of grassland (Isolated) were analyzed separately largely because of the isolation variable (distance to block of grassland), but also because of other landscape composition and configuration variables.

I examined how predator presence was influenced by various landscape features within 500 meters of a sample unit. This buffer distance was based partially on home range sizes of foxes (Storm 1965, Ables 1969, Storm et al. 1976, Sargeant et al. 1987, Trewhellan et al. 1988), raccoons (Glueck et al. 1988) and skunks (Bjorge et al. 1981, Greenwood et al. 1985), but also considered the home range sizes of nesting ducks (Gilmer et al. 1975) and pheasants (Clark et al. 1999).

The GIS was used to measure *a priori* selected landscape variables within the 500-m buffer distance around sample unit locations. On isolated sample units, the natural logarithm of the distance (m) to grassland block (*dgrass*), farmstead (*dfarm*), and wooded habitat (*dwood*), the area (ha) of wooded habitat (*awood*), agricultural grasslands (pasture and hay) (*apast*), and managed grasslands (CRP, WMA, WPA) (*agrass*), the length (100-m units) of strip habitat (road ditches and fences combined) (*lstrip*), and the number of farms (*nfarm*) were measured as predictor variables. When modeling predator activity around the edge of blocks of grassland, I dropped distance to grassland block, area of grassland, distance to farmstead and length of strip habitat. These variables were replaced by the edge density (*edgrass*) of managed grassland, the perimeter of wetland edge (*pwet*),

Figure 2. Sample unit locations from 3 strata (edge, near, far) around the Eagle Lake WPA in Hancock County, Iowa during the summers of 1999 and 2000.


Sample Units
E Edge
F Far (> 500-m)
N Near (< 500-m)
Land use
drainage ditch
farmstead
fence / strip
grassland
hay / pastureland
municipality
road
row cropland
water
woodland
N
W
E
S
500 0 500 1000 1500 2000 2500 Meters

number of wetlands (*nwet*) and shape (convex corner, concave corner, straight side of block of grassland) of grassland edge (*shape*) for modeling predator activity around the edge of blocks of grassland. Distance measurements were log transformed to increase normality and length measurements were converted to 100-m units so that they were more closely scaled to area measurements.

Statistical Analysis

For each group of samples (edge and isolated), I used multiple logistic regression with repeated measures on sample units to test the relative importance and influence of landscape variables on the activity of individual predators and in aggregate. The raw response variable (p) was the presence of at least 1 predator track at a sample unit location after 2 nights of exposure. The responses were modeled on the logit scale ($Y_{species}$ = log (p / 1-p) = f(landscape variables)).

Akaike's Information Criterion values, corrected for small sample size (AIC_C; Burnham and Anderson 1998:51), were calculated for all possible model combinations from the 8 variable general models and then used to calculate ΔAIC_C values for each model. Goodness-of-fit statistics and an index of overdispersion ($\hat{c} = \chi^2 / df$) were calculated from the group global model and used to determine if the variables adequately explained the variation in the data (Burnham and Anderson 1998). When data is overdispersed ($\hat{c} > 4$), precision is over-estimated.

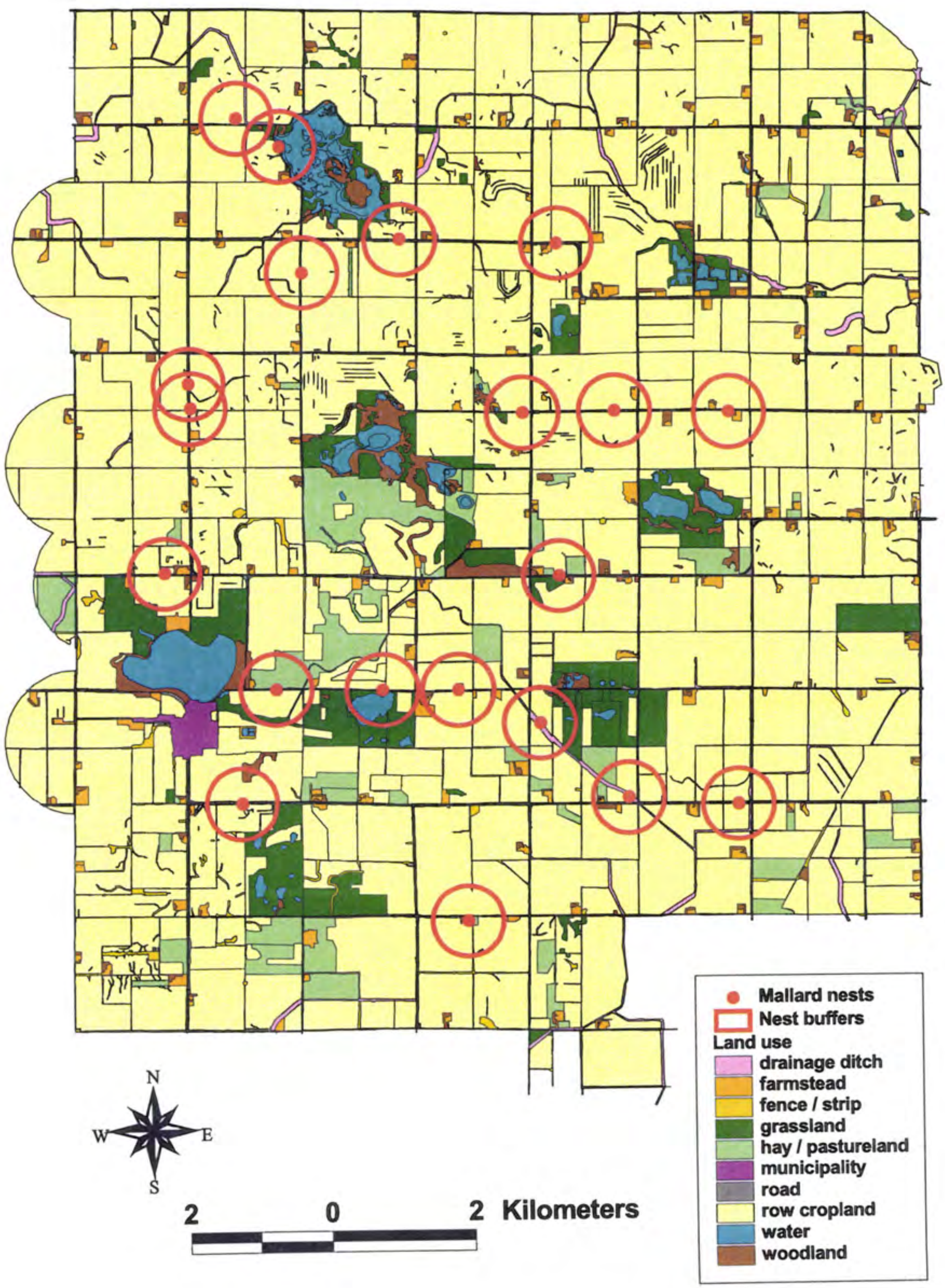
The best-fit models for individual species and for all predators combined were selected using model ΔAIC_C values. Akaike weights (Burnham and Anderson

1998:124, Eq. 4.2) were calculated from the ΔAIC_C values for each model and used to determine the relative importance of each variable (Burnham and Anderson 1998:141). Models with $\Delta AIC_C < 2$ all fit the data well and were reweighted and normalized so the weighted average (Burnham and Anderson 1998:133, Eq. 4.6) and standard error (Burnham and Anderson 1998:135, Eq. 4.9) for each parameter remaining in the models could be calculated.

For isolated sample units, the weighted average parameter estimates were then used in the best-fit model to predict the probability of predator presence from landscape variables within a 500 m buffer around 20 locations (Fig. 3) that were a sub-sample of real mallard (*Anas platyrhynchus*) nests in the study area (Dodici 2001). Half of the nests were < 500 m and half were ≥ 500 m from a block of grassland. Back transformation from the logit scale to a proportion was required to estimate the probability of predator presence and was calculated as [$p = 1 / (1 + e^{-Y_{species}})$]. Probabilities of predator presence were not determined from edge models because duck nests were not available along the edges of blocks of grassland and comparisons between estimated predator presence and nesting success could therefore not be made.

Program CONTRAST (Hines and Sauer 1989) was used to estimate daily nest survival ($\hat{S}_d$) and standard errors on a sub-sample of nests that were near and far from a block of grassland. Daily survival estimates were converted to a 2-day nest mortality ($1 - \hat{S}_d^2$) so that it was more closely related to probability of predator presence. Mortality estimates were contrasted with estimated probability of

Figure 3. Duck nests and 500 m buffers in the northern Iowa predator study area during the summers of 1999 and 2000.



Mallard nests
Nest buffers
Land use
drainage ditch
farmstead
fence / strip
grassland
hay / pastureland
municipality
road
row cropland
water
woodland
N
S
E
W
2
0
2 Kilometers

predator presence to associate predator activity with risk of nest failure and to confirm support for each model.

Predator movement direction was assessed from individual tracks and the predominant trail on sample units. Sample units where I could not confidently determine the direction of predator movement were excluded from movement analyses. The proportion of predator movement perpendicular (into or out of the grassland habitat) was compared and contrasted to parallel movement on sample units. Sample unit type (road ditch, drainage ditch, block side, convex corner, concave corner), block type (block side, convex corner, concave corner) and shape of the edge of a block of grassland (block side, block corner) were examined to determine if individual predator species movement was affected by these features.

Results

Predator activity differed significantly between edge, near and far sample locations ($\chi^2 = 23.94$, df = 2, $P < 0.001$). Sample units near blocks of grassland had the highest combined predator activity, whereas units at the edges, and far from blocks of grassland showed increasingly less activity (Fig. 4). There were significant differences in sample unit type (road ditch, drainage ditch, block side, convex corner, concave corner) use by skunk ($\chi^2 = 12.214$, df = 4, $P = 0.016$), raccoon ($\chi^2 = 12.632$, df = 4, $P = 0.013$), fox ($\chi^2 = 19.882$, df = 4, $P < 0.001$) and all predators combined ($\chi^2 = 19.758$, df = 4, $P < 0.001$) (Table 2). These behavioral

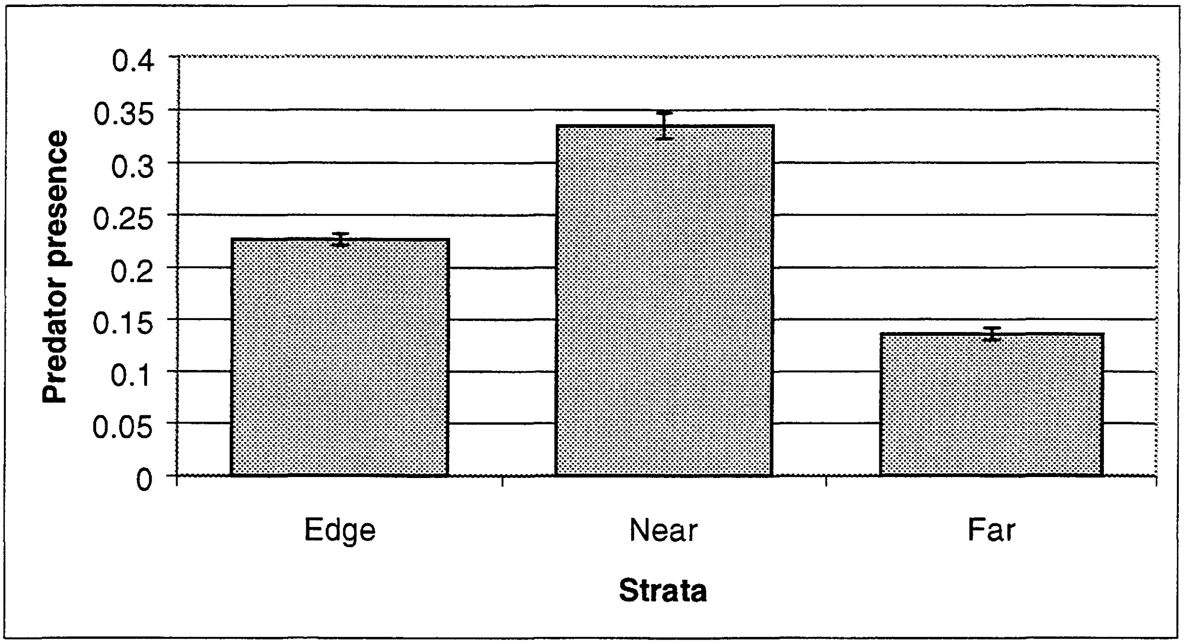


Figure 4. Predator presence (± SE) on sample units located at the edges, near (< 500 m) and far (> 500 m) from blocks of grassland in northern Iowa during the summers of 1999 and 2000.

Table 2. Proportion of predator presence on sample units (road ditch, drainage ditch, block side, convex and concave corners) in northern Iowa during the summers of 1999 and 2000.

	Skunk		Raccoon		Fox		All	
	p	SE(p)	p	SE(p)	p	SE(p)	p	SE(p)
Road Ditch	0.0960	0.0148	0.0429	0.0102	0.0682	0.0127	0.2652	0.0222
Drainage Ditch	0.0352	0.0131	0.0352	0.0131	0.0251	0.0111	0.1457	0.0251
Convex Corner	0.0714	0.0184	0.0969	0.0212	0.0867	0.0202	0.2959	0.0327
Concave Corner	0.0605	0.0152	0.0403	0.0125	0.0202	0.0089	0.1855	0.0247
Block Side	0.0380	0.0124	0.0338	0.0118	0.0970	0.0193	0.1983	0.0260
Corners	0.0653	0.0117	0.0653	0.0117	0.0495	0.0103	0.2342	0.0201

differences among predators using the edges of grassland blocks provided evidence that these sample units should be considered separately from isolated sample units.

When only sample units on the edges of blocks of grassland (side, convex, concave) were considered, raccoons (χ^2 = 9.825, df = 2, P = 0.007), foxes (χ^2 = 13.511, df = 2, P < 0.001) and all predators combined (χ^2 = 8.892, df = 2, P = 0.012) used these types differently, whereas skunks did not (χ^2 = 2.441, df = 2, P = 0.295). When only edge shape was considered (block corner vs. block side), only foxes showed significant differences in activity (χ^2 = 5.649, df = 1, P = 0.017) with a preference for block sides. Skunk (χ^2= 2.192, df = 1, P = 0.139) and raccoon (χ^2 = 2.995, df = 1, P = 0.083) activity was greater at corners, but not significantly. When all predators were combined, there were no significant differences in activity due to edge shape (χ^2 = 1.155, df = 1, P = 0.282) because of the opposing effects of the individual predators.

<u>Isolated Sample Units</u>

Of the possible 595 sample unit-nights, skunk tracks were present at 45, fox tracks were present at 32, raccoon tracks were present at 24, domestic dog tracks were present at 4 and none were visited by domestic cat. On 42 occasions, visible tracks could not be identified to species, but were included in total predator activity.

I did not attempt to interpret presence as a direct measure of abundance because individual predator species may react differently to the sample unit.

Skunk - Distance to a block of grassland and number of farmsteads were the most important variables influencing skunk activity. Based on variable importance, distance to a block of grassland was 1.5 times more important than the number of farms and 2.5 to 4 times more important than other variables in the global model for explaining skunk activity (Fig. 5). The goodness of fit statistics for the skunk global model (Pearson χ^2 = 581.75, df = 586, P = 0.5418) indicated a good fit to the data and no evidence of overdispersion ($\hat{c}$ = 0.993). Each of the best-fit models (ΔAIC_C < 2) for skunk activity included the distance to a block of grassland, whereas other variables in the best-fit models included the number of farms, area of pastureland and length of strip habitat. Akaike weights indicated twice the support for a model that included both distance to a block of grassland and the number of farms compared to a model that only included distance to a block of grassland (Table 3). The average parameter estimates and standard errors for the above variables were: $\hat{\beta}_{dgrass} = -0.2596$ (SE($\hat{\beta}_{dgrass}$) = 0.0031), $\hat{\beta}_{nfarm} = 0.3343$ (SE($\hat{\beta}_{nfarm}$) = 0.0409), $\hat{\beta}_{apast} = 0.0231$ (SE($\hat{\beta}_{apast}$) = 0.0003) and $\hat{\beta}_{lstrip} = -0.0179$ (SE($\hat{\beta}_{lstrip}$) = 0.0001) respectively. Using the average parameter estimates the best-fit model for skunk activity was Y_{skunk} = -1.1952 - 0.2596 (dgrass) + 0.3343 (nfarm).

Raccoon - Importance of landscape variables influencing raccoon activity were more closely related than for skunk, but the distance to woodland and the area

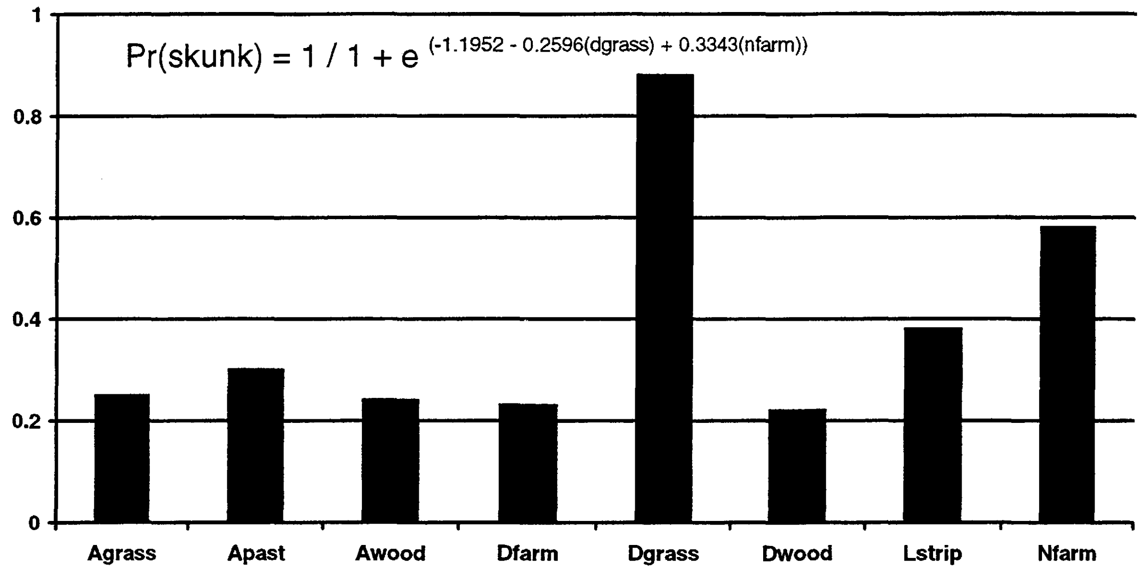


Figure 5. Relative importance of landscape variables and the best-fit model for predicting skunk activity on isolated sample units.

Table 3. Akaike Information Criterion corrected for small sample sizes and model weights for best-fit skunk presence models ($\Delta AIC_C < 2$) on isolated sample units in northern Iowa during the summers of 1999 and 2000.

Parameters included in model	AIC_C	ΔAIC_C	w_i
dgrass, nfarm	308.6246	0.0000	0.3531
dgrass, nfarm, lstrip	309.9373	1.3127	0.1832
dgrass	309.9800	1.3554	0.1793
dgrass, lstrip	310.3284	1.7038	0.1506
dgrass, nfarm, apast	310.5658	1.9412	0.1338

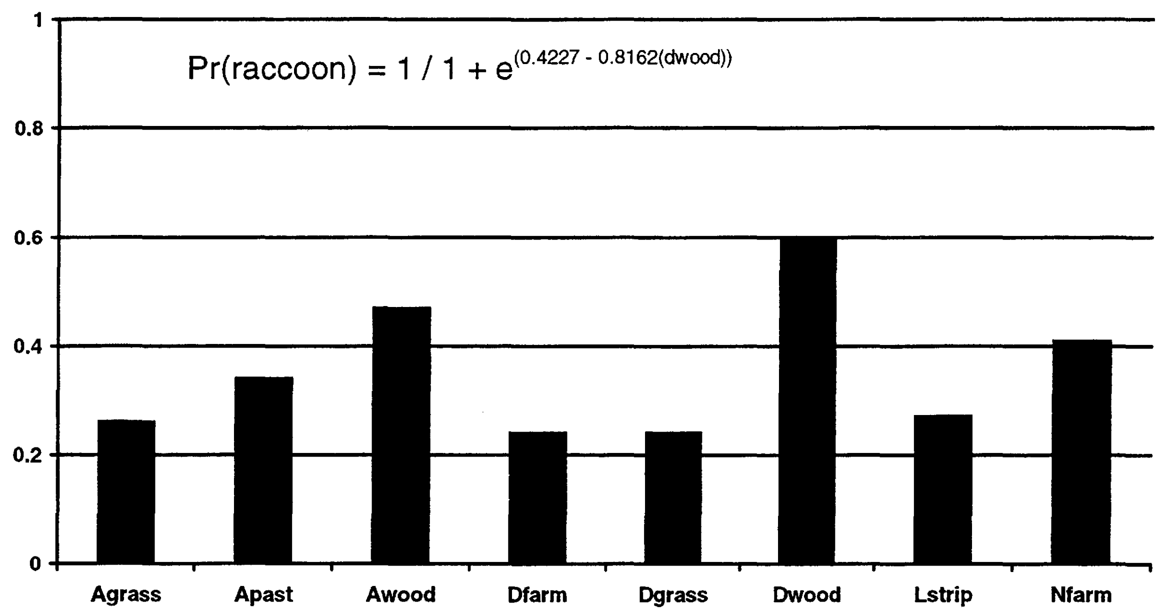


Figure 6. Relative importance of landscape variables and the best-fit model for predicting raccoon activity on isolated sample units.

of woody cover were more influential than other variables in the global model (Fig. 6). For the raccoon global model, the goodness of fit statistics (Pearson χ^2 = 551.22, df = 586, P = 0.8455) indicated a good fit to the data and no evidence of overdispersion ($\hat{c}$ = 0.941). Variables that occurred in the best-fit models (ΔAIC_C < 2) for raccoon activity included the number of farms, distance to woody cover, area of woodland, area of pastureland and length of strip habitat (Table 4). Although area of woodland was nearly as important as distance to woodland, Akaike weights show nearly 2x the support for the model including only the distance to woodland when compared to the model that contained only the area of woodland. The addition of the number of farms to the distance to woodland model actually reduced model support. The average parameter estimates and their standard errors for the

Table 4. Akaike Information Criterion corrected for small sample sizes and model weights for best-fit raccoon presence models ($\Delta AIC_C < 2$) on isolated sample units in northern Iowa during the summers of 1999 and 2000.

Parameters included in model	AIC_C	ΔAIC_C	w_i
dwood	195.0447	0.0000	0.2603
nfarm, dwood	195.5162	0.4715	0.2056
awood	196.1656	1.1209	0.1486
nfarm, awood	196.1934	1.1487	0.1466
dwood, apast	196.3234	1.2977	0.1360
dwood, lstrip	196.9006	1.8559	0.1029

above variables were: $\hat{\beta}_{nfarm} = -0.3435$ ($SE(\hat{\beta}_{nfarm}) = 0.0166$), $\hat{\beta}_{dwood} = -0.8162$ ($SE(\hat{\beta}_{dwood}) = 0.0275$), $\hat{\beta}_{awood} = 0.5338$ ($SE(\hat{\beta}_{awood}) = 0.0101$), $\hat{\beta}_{apast} = 0.0334$ ($SE(\hat{\beta}_{apast}) = 0.0002$) and $\hat{\beta}_{lstrip} = -0.0129$ ($SE(\hat{\beta}_{lstrip}) = 0.0001$) respectively. Using the average parameter estimates the best-fit model for raccoon activity was $Y_{coon} = 0.4227 - 0.8162(dwood)$.

Fox - The area of pastureland was the single most important variable influencing red fox activity, but distance to the nearest farmstead and length of strip habitat were also important for explaining activity (Fig. 7). The red fox global model goodness of fit statistics (Pearson $\chi^2 = 601.13$, df = 586, $P = 0.3236$) indicated a

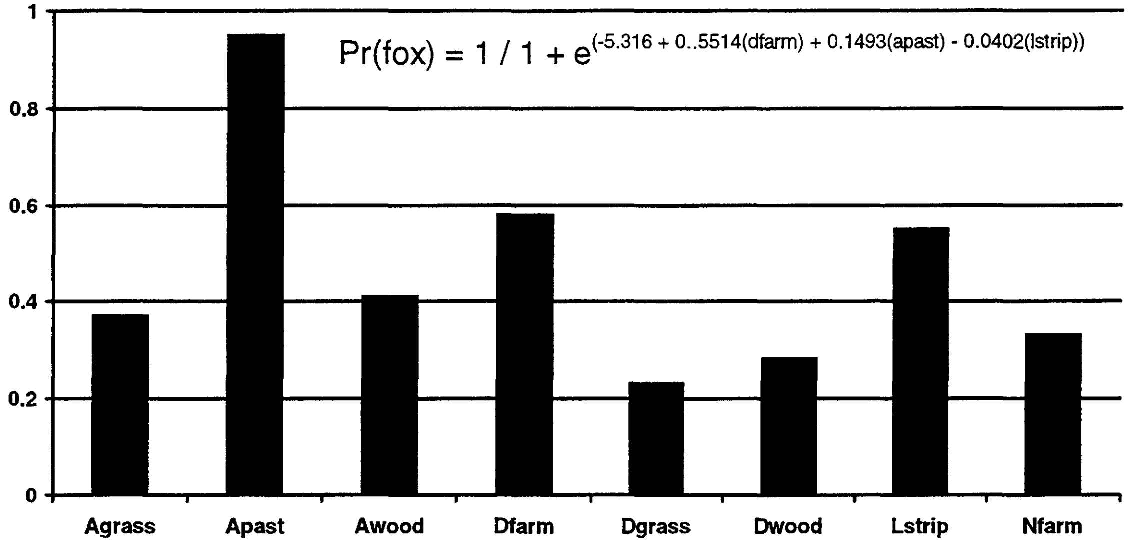


Figure 7. Relative importance of landscape variables and the best-fit model for predicting fox activity on isolated sample units.

good fit to the data and no evidence of overdispersion ($\hat{c}$ = 1.026). Each of the best-fit models ($\Delta AIC_C < 2$) for fox activity included the area of pastureland, while other variables included the number of farms, distance to farmstead, area of grassland, area of woodland and length of strip habitat (Table 5). Akaike weights supported the 3 variable model that included length of strip more than a model that only included area of pastureland and distance to the nearest farmstead. The average parameter estimates and their standard errors for the above variables were: $\hat{\beta}_{apast} = 0.1493$ (SE($\hat{\beta}_{apast}$) = 0.0006), $\hat{\beta}_{nfarm} = 0.2423$ (SE($\hat{\beta}_{nfarm}$) = 0.0096), $\hat{\beta}_{dfarm} = 0.5514$ (SE($\hat{\beta}_{dfarm}$) = 0.0294), $\hat{\beta}_{agrass} = 0.0152$ (SE($\hat{\beta}_{agrass}$) = 0.0000), $\hat{\beta}_{awood}$ = -0.3528, (SE($\hat{\beta}_{awood}$) = 0.0258) and $\hat{\beta}_{lstrip} = -0.0402$ (SE($\hat{\beta}_{lstrip}$) = 0.0005)

Table 5. Akaike Information Criterion corrected for small sample sizes and model weights for best-fit fox presence models ($\Delta AIC_C < 2$) on isolated sample units in northern Iowa during the summers of 1999 and 2000.

Parameters included in model	AIC_C	ΔAIC_C	w_i
dfarm, apast, lstrip	240.1006	0.0000	0.2513
dfarm, apast	240.6561	0.5555	0.1904
nfarm, dfarm, apast	241.5193	1.4187	0.1236
nfarm, dfarm, apast, lstrip	241.5549	1.4543	0.1215
awood, apast, lstrip	241.6570	1.5564	0.1154
dfarm, awood, apast, lstrip	241.8562	1.7556	0.1045
dfarm, agrass, apast, lstrip	242.0828	1.9822	0.0933

respectively. Using the average parameter estimates the best-fit model for fox activity was $Y_{fox} = -5.3160 + 0.5514\,(\text{dfarm}) + 0.1493\,(\text{apast}) - 0.0402\,(\text{lstrip})$.

All predators - Distance to a block of grassland, length of strip habitat and area of pastureland were more important than other variables to explain the activity of all predators (Fig. 8). When all predators were combined the goodness of fit statistics for the global model (Pearson $\chi^2 = 586.25$, df = 586, $P = 0.4893$) indicated a good fit to the data and no evidence of overdispersion ($\hat{c} = 1.001$). Each of the best-fit models ($\Delta AIC_C < 2$) for predator activity included isolation and length of strip habitat (Table 6). Best-fit models also included distance to nearest farm, and

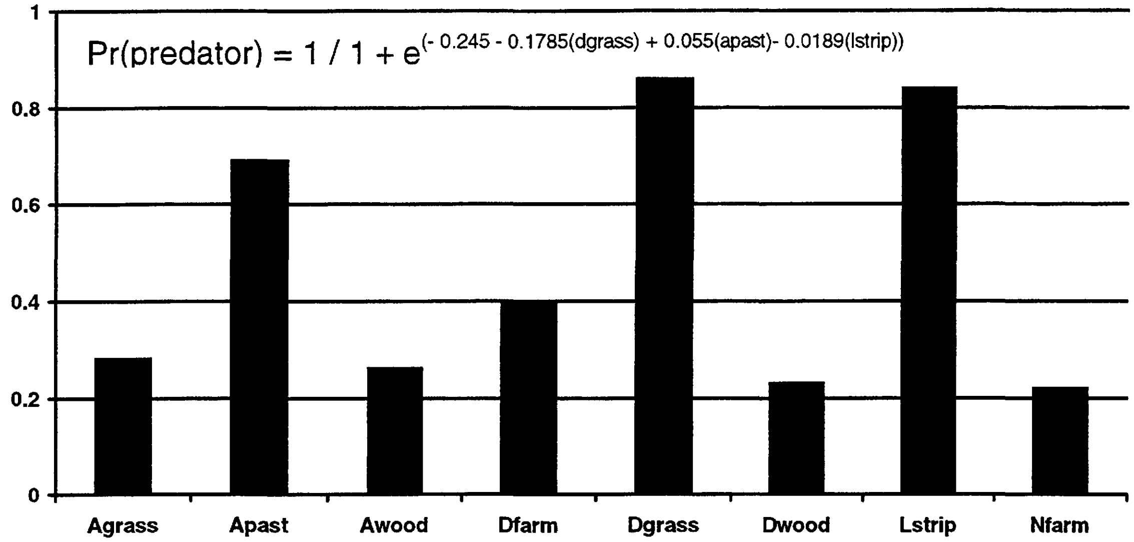


Figure 8. Relative importance of landscape variables and the best-fit model for predicting predator activity on isolated sample units.

Table 6. Akaike Information Criterion corrected for small sample sizes and model weights for best-fit combined predator presence models ($\Delta AIC_C < 2$) on isolated sample units in northern Iowa during the summers of 1999 and 2000.

Parameters included in model	AIC_C	ΔAIC_C	w_i
dgrass, apast, lstrip	605.5863	0.0000	0.3689
dgrass, dfarm, apast, lstrip	605.6074	0.0211	0.3650
dgrass, lstrip	606.2388	0.6525	0.2662

area of pastureland (Table 6). The average parameter estimates and their standard errors for the above variables were: $\hat{\beta}_{dgrass} = -0.1785$ (SE($\hat{\beta}_{dgrass}$) = 0.0022), $\hat{\beta}_{lstrip} = -0.0189$ (SE($\hat{\beta}_{lstrip}$) = 0.0001), $\hat{\beta}_{dfarm} = 0.2265$ (SE($\hat{\beta}_{dfarm}$) = 0.0184) and $\hat{\beta}_{apast} = 0.0550$ (SE($\hat{\beta}_{apast}$) = 0.0005) respectively. Using the average parameter estimates the best-fit model for predator activity was $Y_{predator} = -0.2450 - 0.1785(dgrass) + 0.0550(apast) - 0.0189(lstrip)$.

Model Predictions - The range of estimated probability of predator presence was similar to the range of predator presence I collected in the field. Estimated probability of predator presence at duck nests located near blocks of grassland for skunk (t = 3.52, df = 12, P = 0.0042), raccoon (t = 3.79, df = 11, P= 0.003) and all predators combined (t = 3.44, df = 9, P = 0.0074) was significantly higher than the probability of predator presence at isolated nest locations. The estimated probability of fox presence was higher, but more variable, on nests near blocks of grassland than on more isolated nests (t = 1.45, df = 9, P = 0.18). Higher probability of predator presence was directly related to significantly higher rates of 2-day mortality on duck nests that were located near blocks of grassland compared to nests that were more isolated (Table 7).

Block Edge Sample Units

Of the possible 681 sample unit-nights, skunk tracks were present at 38, fox tracks were present at 45, raccoon tracks were present at 37, domestic dog tracks

Table 7. Estimated 2-day nest mortality (S.E) and mean probability of predator presence (S.E.) for duck nests that were located near (< 500-m) and far (>500-m) from a block of grassland in northern Iowa during the summers of 1999 and 2000.

		Probability of presence			
	Nest mortality	Skunk	Raccoon	Fox	All
Near	0.203 (0.060)	0.127 (0.015)	0.019 (0.003)	0.139 (0.073)	0.231 (0.032)
Far	0.061 (0.022)	0.068 (0.007)	0.009 (0.001)	0.033 (0.006)	0.120 (0.000)

were present at 3, mink (*Mustela vison*) or weasel (*Mustela spp.*) tracks were present at 3, opossum (*Didelphis marsupialis*) tracks were present at 1 and none were visited by domestic cat. On 39 occasions, visible tracks could not be identified to any one of these species, but are included in total predator activity.

Skunk - The most important variable influencing skunk activity was the number of wetlands in the surrounding habitat. Based on variable importance, the number of wetlands was 2 to nearly 4 times more important than other variables in the general model for explaining skunk activity (Fig. 9). The goodness of fit statistics for the skunk global model (Pearson χ^2 = 673.39, df = 672, P = 0.4777) indicated a good fit to the data and no evidence of overdispersion ($\hat{c}$ = 1.00). Each of the best-fit models ($\Delta AIC_C < 2$) for skunk activity around block edges included the number of wetlands (Table 9). Akaike weights provided additional support that a single parameter model including the number of wetlands was the most

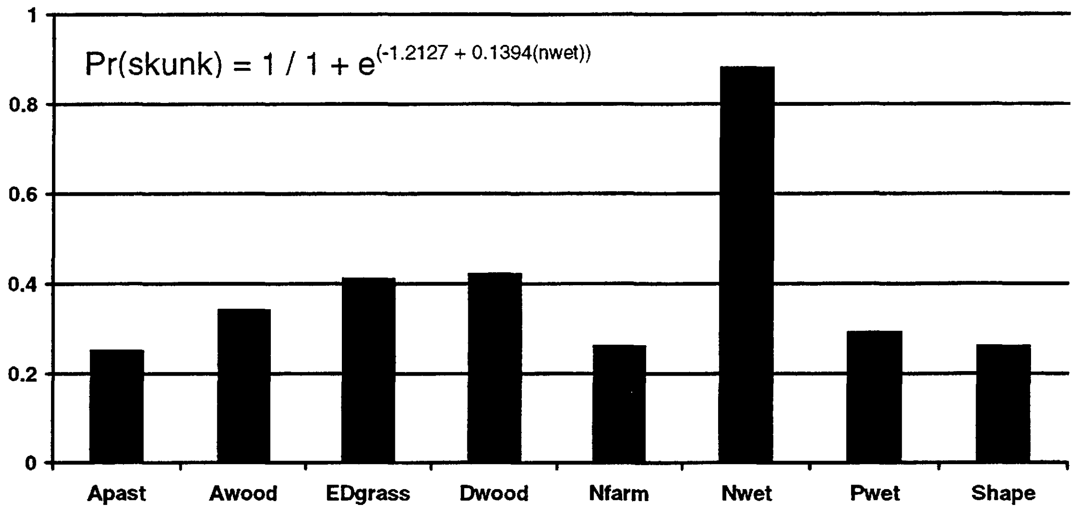


Figure 9. Relative importance of landscape variables and the best-fit model for predicting skunk activity on block edge sample units.

Table 8. Akaike Information Criterion corrected for small sample sizes and model weights for best-fit skunk presence models ($\Delta AIC_C < 2$) of sample units along the edge of blocks of grassland in northern Iowa during the summers of 1999 and 2000.

Parameters included in model	AIC_C	ΔAIC_C	w_i
nwet	280.8367	0.0000	0.2082
nwet, dwood	281.2269	0.3902	0.1713
nwet, awood	281.4088	0.5721	0.1564
nwet, edgrass	281.4715	0.6348	0.1516
nwet, awood, edgrass	281.8990	1.0623	0.1224
nwet, dwood, edgrass	282.2845	1.4478	0.1009
nwet, apast, pwet	282.5314	1.6947	0.0892

appropriate model. The average parameter estimates and their standard errors for the included variables were: $\hat{\beta}_{nwet}$ = 0.1394 (SE($\hat{\beta}_{nwet}$) = 0.0146), $\hat{\beta}_{dwood}$ = -0.2470 (SE($\hat{\beta}_{dwood}$) = 0.0158), $\hat{\beta}_{awood}$ = 0.0702 (SE($\hat{\beta}_{awood}$) = 0.0021), $\hat{\beta}_{apast}$ = 0.0114 (SE($\hat{\beta}_{apast}$) = 0.0209), $\hat{\beta}_{edgrass}$ = -6.9838 (SE($\hat{\beta}_{edgrass}$) = 19.8531) and $\hat{\beta}_{pwet}$ = 0.0001 (SE($\hat{\beta}_{pwet}$) = 0.0003) respectively. Using the average parameter estimates the best-fit model for skunk activity along the edge of blocks of grassland was Y_{skunk} = -1.2127 + 0.1394(nwet).

Raccoon - Landscape variables influencing raccoon activity were more closely related and more unpredictable than for skunk, but the number of farmsteads, distance to woodland, and area of woodland had higher variable important indices than other variables in the model (Fig. 10). Variable importance suggests that the number of farmsteads, distance to woodland and area of woodland were 1.5 to over 2 times more influential than other variables in explaining raccoon activity. However, the goodness of fit statistics for the general raccoon model (Pearson χ^2 = 1154.69, df = 672, $P < 0.001$) indicated a poor fit to the data with no evidence of overdispersion ($\hat{c}$ = 1.72). Due to the poor fit of the general model a predictive model was not calculated.

Fox - The number of farmsteads, perimeter of wetland edge and to a lesser extent the area of pastureland were the most important variables influencing red fox activity along edges of blocks of grassland (Fig. 11). The number of wetlands was

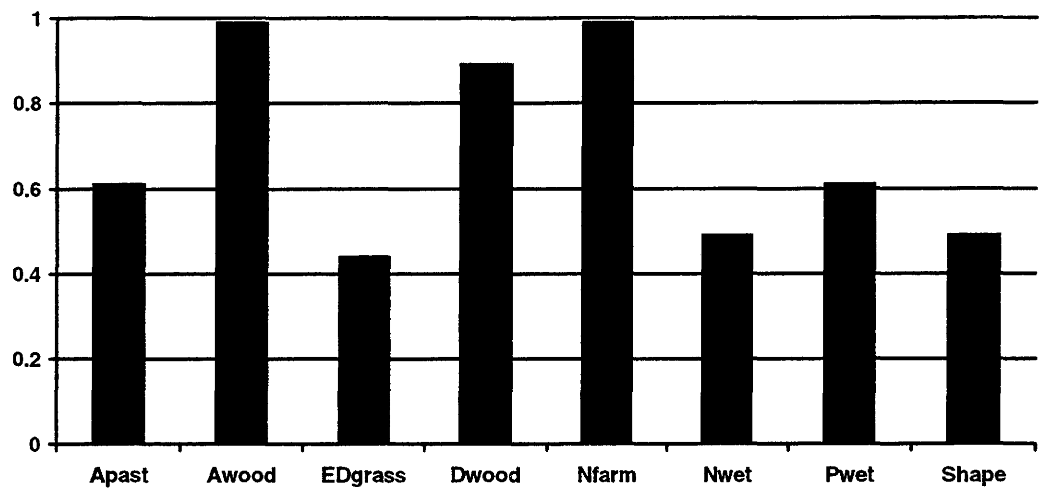


Figure 10. Relative importance of landscape variables influencing raccoon activity on block edge sample units.

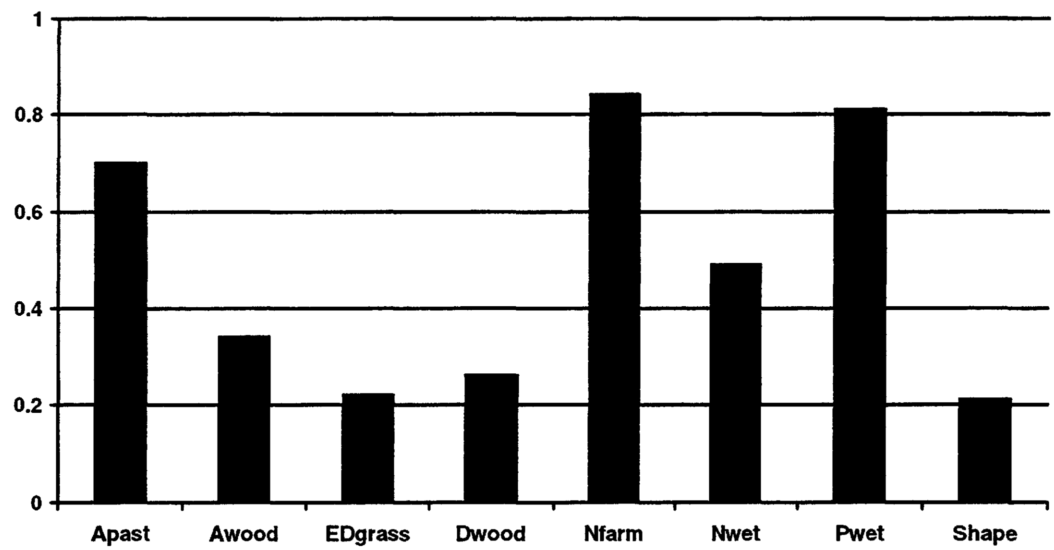


Figure 11. Relative importance of landscape variables influencing fox activity on block edge sample units.

slightly better than the remaining variables. Number of farmsteads, perimeter of wetland edge and area of pastureland were nearly 1.5 times more important than the number of wetlands and 2 times more important than all other variables in the model. However, the goodness of fit statistics for the general fox model (Pearson $\chi^2 = 924.86$, df = 672, $P < 0.001$) indicated a poor fit to the data, with no evidence of overdispersion ($\hat{c} = 1.37$). Due to the poor fit of the general model, a predictive model for fox activity was not calculated.

All predators - When all predators were combined, area of pastureland and distance to woodland were the most important variables in the general model (Fig. 12). The goodness of fit statistics for the global model (Pearson $\chi^2 = 701.77$, df = 672, $P = 0.2065$) indicated a good fit to the data and no evidence of overdispersion ($\hat{c} = 1.04$). There were only two models that fit adequately ($\Delta AIC_C < 2$), and each included the distance to woodland, area of woodland, and area of pastureland variables (Table 10). The model that included edge density of grassland had nearly 1.5x the support as the model without that variable. The average parameters and their standard errors for the variables included in the best-fit models were: $\hat{\beta}_{dwood} = -0.4568$ ($SE(\hat{\beta}_{dwood}) = 0.6152$), $\hat{\beta}_{awood} = -0.0469$ ($SE(\hat{\beta}_{awood}) = 0.0021$), $\hat{\beta}_{apast} = -0.0929$ ($SE(\hat{\beta}_{apast}) = 0.0009$), and $\hat{\beta}_{edgrass} = -5.9201$ ($SE(\hat{\beta}_{edgrass}) = 2.5759$ respectively. Using the average parameter estimates the best-fit model for block edge predator activity is $Y_{predator} = 0.9706 - 0.4568(dwood) - 0.0469(awood) - 0.0929(apast) - 5.9201(edgrass)$.

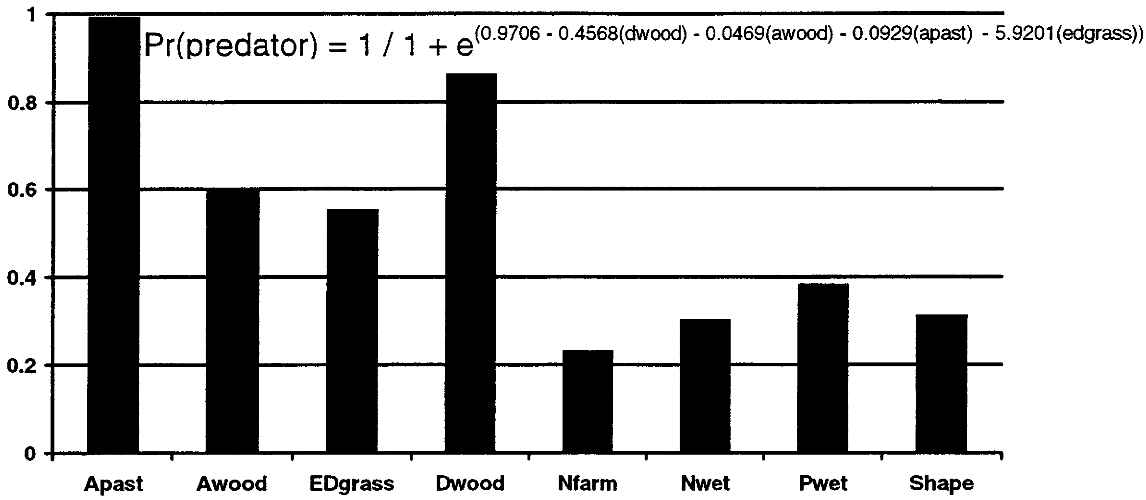


Figure 12. Relative importance of landscape variables and the best-fit model for predicting predator activity on block edge sample units.

Table 9. Akaike Information Criterion corrected for small sample sizes and model weights for best-fit predator presence models ($\Delta AIC_C < 2$) of sample units along the edge of blocks of grassland in northern Iowa during the summers of 1999 and 2000.

Parameters included in model	AIC_C	ΔAIC_C	w_i
dwood, awood, apast, edgrass	708.5543	0.0000	0.5898
dwood, awood, apast	709.2802	0.7259	0.4102

Movement Direction

Predator movements (perpendicular vs. parallel) relative to the edges of the grassland - row cropland interface, differed significantly among road ditch, drainage ditch, block side, convex corner and concave corner samples (χ^2 = 65.381, df = 4, P < 0.001). Nearly half of the observed difference resulted from the increased proportion of perpendicular movements by predators into and out of grasslands at convex and concave corners (Cell χ^2 = 11.48, and 17.97 respectively). Only 15% of predator movement direction along straight edges (road ditch, drainage ditch, block side) was perpendicular to the grassland habitat, whereas perpendicular movements accounted for more than 74% and 80% along convex and concave edges respectively depending on species (Table 11).

Discussion

Individual predators were influenced differently by landscape composition and configuration variables, however some general relationships were consistent. High predator activity on sample units near (< 500-m), and low activity far (> 500-m) from blocks of grassland support an inverse relationship between isolation and activity. Predator behavior was focused near blocks of grassland and extended into the surrounding habitats. A similar relationship between activity and distance into the grassland habitat may exist and has often been inferred from nesting studies. Lower activity along the edge of blocks of grassland, when compared to near blocks of grassland may be a result of differing amounts of grassland habitat. Along the

Table 10. Mean proportion (± SE) of movement perpendicular to the grassland - row cropland edge by predators on sample units where tracks were identified in northern Iowa during the summers of 1999 and 2000.

	Road ditch			Drainage ditch			Block side			Convex corner			Concave corner		
	n	**mean**	**std err**	**n**	**mean**	**std err**	**n**	**mean**	**std err**	**n**	**mean**	**std err**	**n**	**mean**	**std err**
Skunk	37	0.0270	0.0270	8	0.0000	0.0000	9	0.0000	0.0000	13	0.8462	0.1042	15	0.9333	0.0667
Raccoon	16	0.0000	0.0000	8	0.0000	0.0000	8	0.1250	0.1250	19	0.7368	0.1038	10	0.9000	0.1000
Fox	25	0.1200	0.0663	6	0.0000	0.0000	23	0.1304	0.0718	17	0.7647	0.1060	05	0.8000	0.2000
All	97	0.0515	0.0226	29	0.0690	0.0479	44	0.0682	0.0384	53	0.7358	0.0611	41	0.8780	0.0517

edge of grasslands, activity may be diluted throughout the more extensive grassland area, whereas near blocks of grassland, activity is concentrated on the narrow strip habitats surrounding the grassland block. At a larger scale, others have identified similar dilution effects in landscapes with increased grassland habitat (Greenwood et al. 1995, Sovada et al. 2000, Phillips et al. *in review*).

Isolated Sample Units

My findings support previous studies that found skunks prefer to forage along agricultural field edges (Verts 1967), surrounding grasslands (Greenwood et al. 1999) and wetlands (Phillips et al. *in review*). As distance from these preferred foraging habitats increased (isolation), skunk activity decreased. Skunks commonly use farmsteads for denning (Lariviere and Messier 1998) which may explain the positive influence of the number of farms on skunk activity.

Woody cover is important raccoon habitat (Pedlar et al. 1997, Dijak and Thompson 2000). Near woody cover raccoon activity was greater than at locations that were far from woody cover. For raccoons, the distance to woodland is a measure of isolation from their preferred habitat and the same negative relationship exists here as I saw between skunk activity and isolation from grassland.

Foxes have been found to select pastureland in some landscapes in North Dakota (Phillips et al. *in review*) which is consistent with my results. Selection of pastureland may be related to selection of large blocks of perennial habitat in general, although movement through, and prey availability would be different in pastureland and managed grassland. Isolation was not a good predictor of fox activity patterns, perhaps because their larger home range and greater movement distances reduce their dependence on any specific block of cover. Foxes also avoided farmsteads, which may be a response to human disturbances.

From the perspective of nest exposure to the 3 major mammalian predators, distance to a block of grassland (isolation) and length of strip habitats were the most influential variables for predicting activity. The inverse influence of isolation on activity may have been even stronger if the distance to woody cover was used as the measure of isolation when raccoon presence was detected. Inclusion of strip habitat length in the best-fit model, suggests that predators may be using road ditches and fence lines as corridors between larger patches of habitat. Pastureland also influenced predator activity, but is likely a function of additional perennial habitat in the area.

The direct relationship between estimated predator activity and nest mortality support and quantify results inferred from previous nesting studies (Gates and Gysel 1978, Andren et al. 1985, Wilcove 1985, Yahner and Scott 1988, Johnson and Temple 1990, Burger et al. 1994, Paton 1994, Andren 1995, Clark et al. 1999). Modeling the probability of predator activity using landscape variables could be very useful in determining nesting areas that are at high risk of predation. Models may also provide a framework for improving existing habitat or allocating new habitat in such a way that predator activity is minimized. However, the importance of predator community cannot be overlooked when using these models. For example, if foxes are the primary predator affecting duck nest success, the model that explicitly addresses fox activity may be more meaningful than one that addresses all predators jointly.

Block Edge Sample Units

My findings support previous studies that found skunks prefer to forage along agricultural field edges (Verts 1967), surrounding grassland (Greenwood et al. 1999) and wetlands (Phillips et al. *in review*). The measured landscape variables did not do well in explaining differences in raccoon or fox activity around the edges of grassland blocks. The positive influence that area of pastureland had on overall predator activity may be a function of additional habitat or due to its use by predators for den locations (Sargeant 1972, Pedlar et al. 1997). Near woodland habitat, within or near blocks of grassland, predator activity was higher, suggesting its importance as a focal point for predator behavior.

Edge Shape

Predators used corners to enter and exit grassland habitat which supports previous findings (Ims 1995) that corners may funnel activity. The increased fox activity along straight grassland edges supports the idea that these features can be used as travel lanes (Andren 1995). The larger home range size of foxes correlates with greater movement distances and these long edges may be an important component influencing home range configuration and interactions with prey populations.

Management considerations

My analyses address the use of landscape features by the primary mammalian waterfowl nest predators in the northern Great Plains. By understanding the predators view of the landscape, wildlife biologists can refine management plans to reduce the effects of nest predation without expensive eradication or exclusion methods.

After the initial loss of habitat, the configuration of the remaining patches becomes more important to the activity of predators. My research supports the importance of core habitat for nesting, but also suggests predator activity is focused around blocks of grassland habitat. Clark et al. (1999) found grassland patches should be > 15.6 hectares to have adequate core area to improve the nesting success of pheasants. In addition, grasslands that contain wetlands may attract predators more so than grasslands without wetlands.

This study indicates that small isolated patches may also have increased nesting success, however, they also have fewer nests. Isolated grassland patches, including roadsides and drainage ditch buffers, may be an additional habitat management tool especially in highly agricultural landscapes. However, the optimum size and isolation distance of patches that provide increased use by nesting birds without attracting predators must be further quantified.

This paper suggests the importance of the configuration of grassland patches in predator activity especially in highly agricultural landscapes where a dilution effect is not possible. Corners of grassland block habitat are very important to predator movement and activity and therefore nesting success. Specific management practices of this habitat feature could be used to reduce patch penetration through the reduction of corners and perhaps increase the size of core area for a patch.

Through the use of GIS and predator modeling, biologists may be able to predict the influence of predators on nesting birds based on landscape composition and configuration. Understanding how predators use different landscape configurations could help managers choose among land use policies that would reduce the influence of predators on nesting birds. Restoration efforts should account for predator activity directly in order to be more effective in managing for higher nesting success of ground nesting birds.

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CHAPTER 3: WHITE-TAILED DEER MOVEMENT AND ACTIVITY IN RELATION TO LANDSCAPE VARIABLES IN NORTHERN IOWA

A paper to be submitted to the Journal of Mammalogy

Aaron K. Kuehl

Abstract

Interest in the behavior, activity and movement direction of white-tailed deer has risen because of increased damage to agricultural crops and an increase in the number of deer-vehicle accidents. By understanding how deer use the landscape managers may be able to identify and reduce potential high damage areas. I estimated activity and movement direction of white-tailed deer (*Odocoileus virginianus*) as a function of landscape variables in northcentral Iowa using un-baited (passive) track stations. Sample units located along the edge of blocks of grassland (block edge) and at various distances away from grassland blocks (isolated) were analyzed separately. Landscape variables within a 1000-m radius of track-station locations were selected and quantified using aerial imagery and a geographic information system for inclusion as predictors in the general models for isolated and block edge sample units. Logistic regression with repeated measures and Akaike weights were used to determine the influence of landscape composition and configuration variables on white-tailed deer activity. Activity was highest along the edges of blocks of grassland and decreased with distance from grasslands (χ^2 = 138.81, df = 2, $P < 0.001$). On isolated sample units, deer activity decreased as distance to woodland increased. Also, on isolated sample units, the area of

pastureland had a small negative influence and area of grassland had a weak positive influence on activity of white-tailed deer. Sample units located along the edges of blocks of grassland were positively influenced by distance to farmstead, whereas distance to woodland, area of woodland, area of grassland, and number of wetlands all had a negative influence on activity. Less than 20% deer movements along straight edges (road ditch, drainage ditch, block side) were into or out of the grassland, whereas 90% of movements at convex and concave edges were into or out of the grassland.

Introduction

Availability, quality and juxtaposition of forage and habitat cover are important to the success of white-tailed deer (Naugle et al. 1997). Agricultural practices across the northern Great Plains have decreased the extent of natural grasslands and increased landscape fragmentation (Ratti and Scott 1991, Reynolds 2000, Ryan 2000). Three major effects of habitat loss and fragmentation are decreased patch size, increased habitat edge (Laurance and Yensen 1991) and increased isolation (Fahrig 1997). In northern Iowa, more than 75% of land use is rowcrop agriculture (Clark et al. *in press*) and the remaining perennial grassland, woodland and wetland habitats exist in a variety of large blocks, small patches and narrow strips of habitat. White-tailed deer have successfully responded to these changes in landscape composition and configuration (Sparrowe and Springer 1970, Zagata 1972, Nixon et al. 1991, Vercauteren and Hygnstrom 1998), and populations may be reaching historic highs (Roseberry and Woolf 1998).

Previous studies have identified various landscape composition variables such as woodland (Beier and McCullough 1990, Gould and Jenkins 1993, Roseberry and Woolf 1998), grassland (Gould and Jenkins 1993, Selting and Irby 1997, Roseberry and Woolf 1998), pastureland (Selting and Irby 1997) and wetland (Gould and Jenkins 1993, Naugle et al. 1997) that may influence the activity of white-tailed deer. In addition to the influence of habitat composition, configuration, such as juxtaposition and distance to cover (Naugle et al. 1997) may also affect activity. Activity and movement direction of white-tailed deer may be influenced by the shape of the edge of blocks of grassland habitat. Corners such as concave edges have been proposed as funnels of activity into a patch of habitat (Ims 1995) with convex corners acting similarly as points of exit or entry into a patch.

There have been many studies of the activity and habitat use by white-tailed deer (Beier and McCullough 1990, Gould and Jenkins 1993, Vercauteren and Hygnstrom 1998), but few have attempted to use landscape features to model activity (Selting and Irby 1997, Roseberry and Woolf 1998) or movement direction. Recently, interest in white-tailed deer movement and activity has risen because of increased damage to agricultural crops (Conover and Decker 1991, Conover 1994) and an increase in the number of deer-vehicle accidents (Hubbard et al. 2000).

I wanted 1) to assess activity and movements of white-tailed deer and 2) to determine how landscape composition and configuration might be quantitatively related to deer activity and movements. My approach was a) to determine the most important landscape variables influencing the level of predator activity using passive tracking stations, b) to build and select models for predicting deer activity given landscape variables, and c) to examine the influence of the edge shape of blocks of grassland habitat on deer movements into and out of grasslands.

Study Area

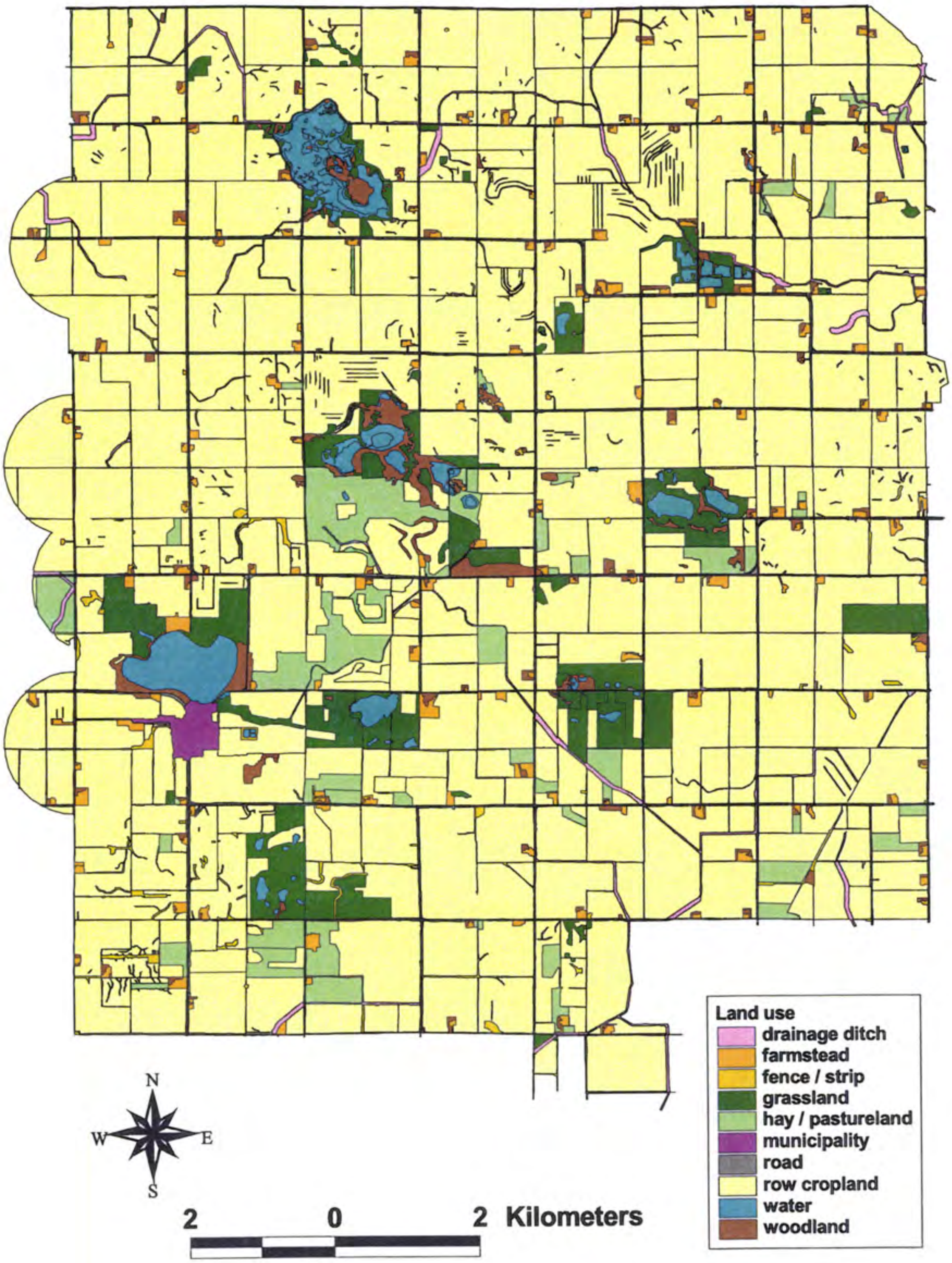
My research was conducted from May through mid July during 1999 and 2000 within the Eagle Lake Wetland Complex, a project area of the North American Wetland Conservation Act, located in the eastern half of the Iowa Prairie Pothole Region in Hancock and Winnebago counties in northcentral Iowa (Fig. 1). The 127 km^2 study area contains a complex of Wildlife Management Areas (WMA), Waterfowl Production Areas (WPA), Conservation Reserve Program (CRP) lands, and agricultural fields (row cropland, hayland, and pastureland). The Iowa Department of Natural Resources (IDNR) manages nearly 700 ha of upland and 800 ha of wetlands in the study area including the lands owned by the U. S. Fish and Wildlife Service (USFWS).

Methods

Deer Activity

Presence and movement direction of white-tailed deer tracks were used to determine relative deer activity and movement at sample unit locations. I modified

Figure 1. Habitat classification for the study area in Hancock and Winnebago Counties in northern Iowa during the summers of 1999 and 2000.



Land use
drainage ditch
farmstead
fence / strip
grassland
hay / pastureland
municipality
road
row cropland
water
woodland
N
W
E
S
2
0
2 Kilometers

the track station technique used by Sargeant et al. (1993) and Sovada et al. (1995) so that I could randomly distribute sample unit locations across the landscape. Sample units were located along the grassland - row cropland edge of road ditches, drainage ditches, sides of blocks of grassland, convex corners of blocks of grassland, and concave corners of blocks of grassland and selected randomly from units within 3 strata.

A sample unit consisted of two sub-units, one placed in the first few rows of row cropland adjacent to the grassland edge and the other was placed 2 m into the grassland habitat. Each sub-unit consisted of three 1-m^2 track stations separated by 3 m with sub-units parallel to the grassland-row cropland edge. The multiple track stations allowed a larger tracking area to be sampled with less disturbance to the habitat, and enabled me to better determine movement direction.

Each track station consisted of finely raked soil with a 3.5 cm white disk placed at its center. When soil conditions were poor, mineral oil was applied to moisten the soil to improve track registration (M.A. Sovada, Northern Prairie Wildlife Research Center, personal communication). A numerical rating (0-5) of track station condition (Table 1) was recorded to control for differences in the ability to detect and identify white-tailed deer tracks.

Sample units were checked after 2 nights of exposure. I selected 2 exposure nights as a compromise between opportunity for deer response and reduction of weather related disturbances.

Table 1. Rating system used to control for differences in track detection rates. Sample units with ratings of 0 and 1 were excluded from analyses.

Rating	Description
1	Soil dry and hard without dust. No chance of track.
2	Soil dry and firm. Thin layer of dust. Tracks detectable.
3	Soil dry, but soft. Tracks identifiable.
4	Soil moist and soft. Tracks easily identified.
5	Soil wet and muddy. Tracks well defined and easily identified.

Habitat and Landscape Variables

Land cover data were recorded from low altitude aerial photography for the entire study area plus a 1.6 km wide buffer around the periphery. Photographs were digitized and georeferenced and ArcInfo / ArcView Geographical Information System (GIS) software was used to map and quantify landscape characteristics. Habitat was classified into one of nine cover types: 1) row cropland, 2) strip grassland (terrace, fence line), 3) drainage ditch, 4) grassland block (WMA, CRP, WPA), 5) hayland and pastureland, 6) water, 7) woodland (including shelterbelts surrounding farmsteads), 8) roads and 9) farmsteads. Classifications were verified by ground observations.

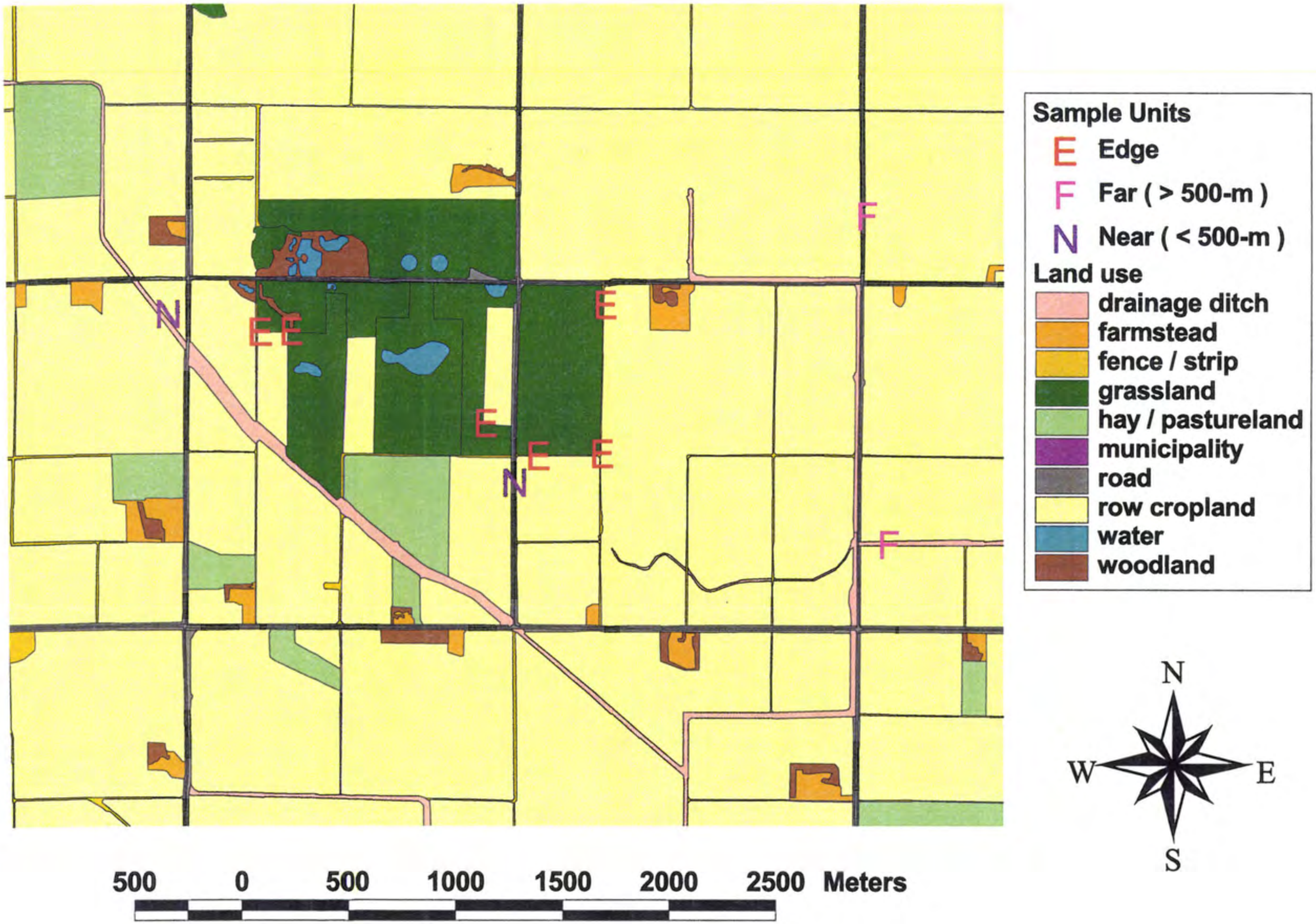
Relating Deer Activity to Landscape Variables

One of my primary interests was the influence that distance away from the nearest block of grassland (isolation) may have on activity of white-tailed deer. Sample units were selected randomly from 3 strata (Edge, Near and Far). Edge sample units were allocated among sides (n = 13), convex corners (n = 11) and concave corners (n = 13) of blocks of grassland. Near sample units were selected from all the possible 9-m sections of gravel road ditch (n = 10) and drainage ditch (n = 5) that were < 500 m from a block of grassland. Far sample units were selected from all the possible 9-m sections of gravel road ditch (n = 12) and drainage ditch (n = 6) that were > 500 m from a block of grassland (Fig. 2). Deer activity along the edges of blocks of grassland (Edge) and deer activity away from the edges of blocks of grassland (Isolated) were analyzed separately largely because of the isolation variable (distance to a block of grassland), but also because of other landscape composition and configuration variables.

I believed that deer presence at isolated sample unit locations could be influenced by landscape features within 1000 m of a sample unit. This buffer distance was based on home range sizes of white-tailed deer (Sparrowe and Springer 1970, Hoskinson and Mech 1976, Larson et al. 1978, Nelson and Mech 1981, Tierson et al. 1985, Beier and McCullough 1990, Naugle et al. 1997, Vercauteren and Hygnstrom 1998).

The GIS was used to measure *a priori* selected landscape variables within the 1000-m buffer distance around sample unit locations. On isolated sample units,

Figure 2. Sample unit locations from 3 strata (edge, near, far) around the Eagle Lake WPA in Hancock County, Iowa during the summers of 1999 and 2000.


Sample Units
E Edge
F Far (> 500-m)
N Near (< 500-m)
Land use
drainage ditch
farmstead
fence / strip
grassland
hay / pastureland
municipality
road
row cropland
water
woodland
N
W
E
S
500 0 500 1000 1500 2000 2500 Meters

the distance (m) to grassland block (*dgrass*), farmstead (*dfarm*), and woodland (*dwood*), the area (ha) of wooded habitat (*awood*), agricultural grasslands (pasture and hay) (*apast*), and managed grasslands (CRP, WMA, WPA) (*agrass*) and the number of farms (*nfarm*) within the 1000-m buffered area were measured for predictor variables. When modeling deer activity around the edge of blocks of grassland, I dropped the distance to grassland block, and replaced it by the number of wetlands (*nwet*) within the buffered area. All other variables were identical for isolated and edge of block of grassland models. Distance measurements were log transformed to increase normality and length measurements were converted to 100-m units so that they were more closely scaled to area measurements.

Statistical Analysis

For each group of samples (edge and isolated), I used multiple logistic regression with repeated measures on presence of white-tailed deer tracks at sample units to test the relative importance and influence of landscape variables on activity. The raw response variable (p) was the presence of at least 1 deer track at a sample unit location after 2 nights of exposure. The responses were modeled on the logit scale ($Y_{deer} = \log (p / 1\text{-}p) = f(\text{landscape variables})$).

Akaike's Information Criterion values, corrected for small sample size (AIC_C; Burnham and Anderson 1998:51), were calculated for all possible model combinations from the 7 variable general model and then used to calculate ΔAIC_C values for each model. Goodness-of-fit statistics and an index of overdispersion ($\hat{c}$

$= \chi^2$ / df) were calculated from the global model and used to determine if the variables adequately explained the variation in the data (Burnham and Anderson 1998). Values of $\hat{c}$ that are greater than 4 are overdispersed and estimates of precision will be over estimated, whereas values closer to 1 are not so affected.

The best-fit models for white-tailed deer were selected using model ΔAIC_C values. Akaike weights (Burnham and Anderson 1998:124, Eq. 4.2) were calculated from the ΔAIC_C values for each model and used to determine the relative importance of each variable (Burnham and Anderson 1998:141). Models with $\Delta AIC_C < 2$ all fit the data well and were re-weighted and normalized so the weighted average (Burnham and Anderson 1998:133, Eq. 4.6) and standard error (Burnham and Anderson 1998:135, Eq. 4.9) for each parameter remaining in the models could be calculated. The weighted average parameter estimates could be used in the best-fit model for predicting the probability of deer presence given landscape variables. Back transformation from the logit scale to a proportion was required to estimate white-tailed deer activity proportions and was calculated as $[1 / 1 + e^{-Y}]$.

Deer movement direction was assessed from individual tracks and the predominant trail on sample units to determine how white-tailed deer moved along the grassland - row-cropland interface. Sample units where I could not confidently determine the direction of movement were excluded from movement analyses. Mean proportions of deer movement direction (into grassland, out of grassland, adjacent to grassland - row-cropland edge) and their standard errors were calculated for sample units and then contrasted relative to sample unit edge shape (convex corner, concave corner, straight edge) which reflected my interest in the influence edge shape had on white-tailed deer movement into or out of a patch of grassland habitat.

Results

White-tailed deer tracks were present on 405 of the total 1312 sample unit-nights. On some occasions it was evident that multiple deer had been present at the sample unit; however, no effort was made to distinguish individual deer based on their tracks. I did not attempt to interpret presence as a direct measure of abundance.

Activity of white-tailed deer differed significantly between sample unit type ($\chi^2 = 144.6$, df = 4, $P < 0.001$; Fig. 3) and strata ($\chi^2 = 138.81$, df = 2, $P < 0.001$; Fig. 4). Activity was highest at sample units along the edge of blocks of grassland, whereas near and far sample units showed increasingly less activity. Deer activity was higher at corner sample unit locations than it was at straight (road ditch, drainage ditch, side of grassland block) locations when all sample units were considered ($\chi^2 = 106.14$, df = 1, $P < 0.001$).

The most important variable influencing activity of white-tailed deer on isolated sample units was the distance to woodland. Based on variable importance, the distance to woodland was nearly 1.5 to 3 times more important than other variables in the general model for explaining deer activity (Fig. 5). The goodness-

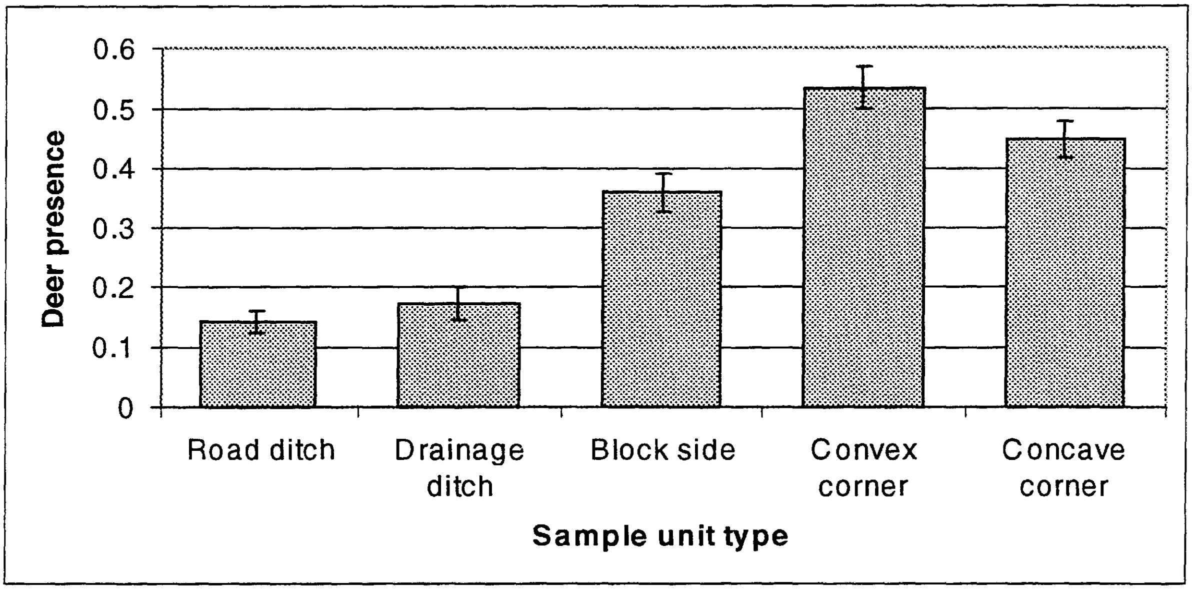


Figure 3. Deer presence (± SE) on sample unit types in northern Iowa during the summers of 1999 and 2000.

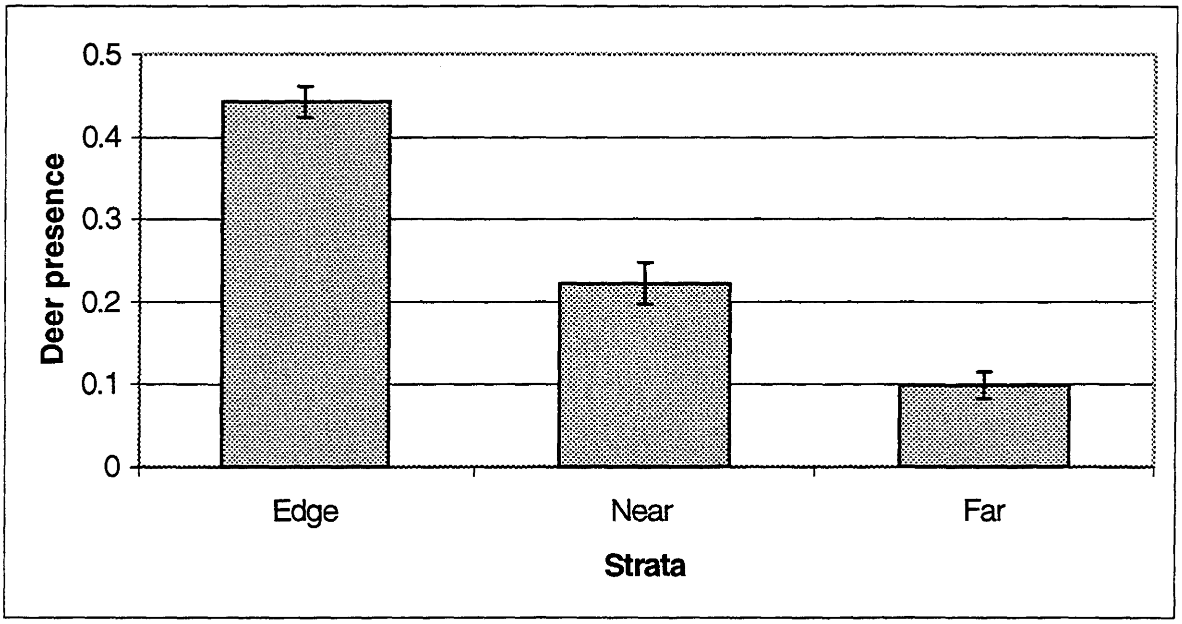


Figure 4. Deer presence (± SE) on sample units located at the edges, near (< 500 m) and far (> 500 m) from blocks of grassland in northern Iowa during the summers of 1999 and 2000.

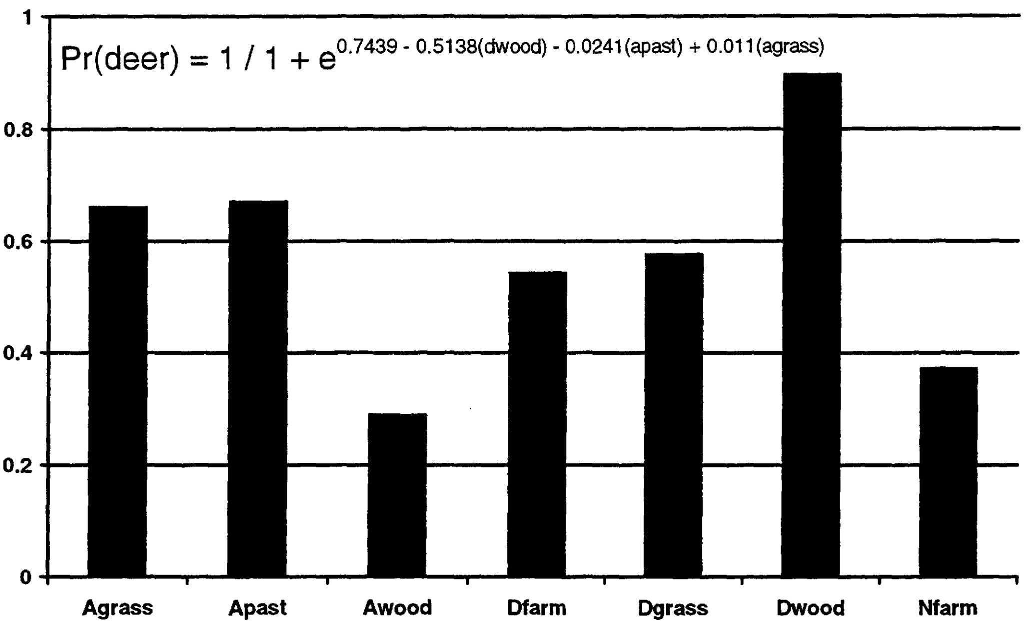


Figure 5. Relative importance of landscape variables and the best-fit model for predicting deer activity on isolated sample units.

of-fit statistics for the global model for activity at isolated sample units (Pearson χ^2 = 613.91, df = 599, P = 0.3277) indicated a good fit to the data and no evidence of overdispersion ($\hat{c}$ = 1.02). Each of the best-fit models ($\Delta AIC_C < 2$) for deer activity included distance to woodland and area of pastureland (Table 2). Akaike weights provided 2x the support for the best-fit model when compared to the next best model. The average parameter estimates and their standard errors for the variables included in the best-fit models were: $\hat{\beta}_{nfarm}$ = 0.1544 (SE($\hat{\beta}_{nfarm}$) = 0.0054), $\hat{\beta}_{dgrass}$ = -0.2266 (SE($\hat{\beta}_{dgrass}$) = 0.0097), $\hat{\beta}_{dfarm}$ = 0.51 (SE($\hat{\beta}_{dfarm}$) = 0.071), $\hat{\beta}_{dwood}$ = -0.5138 (SE($\hat{\beta}_{dwood}$) = 0.0172), $\hat{\beta}_{apast}$ = -0.0241 (SE($\hat{\beta}_{apast}$) = 0.0001) and $\hat{\beta}_{agrass}$ = 0.011

Table 2. Akaike Information Criterion corrected for small sample sizes and model weights for best-fit models of white-tailed deer presence models ($\Delta AIC_C < 2$) at isolated sample units in northern Iowa during the summers of 1999 and 2000.

Parameter included in model	AIC_C	ΔAIC_C	w_i
dwood, apast, agrass	500.2888	0.0000	0.3938
nfarm, dgrass, dfarm, dwood, apast	501.6182	1.3294	0.2026
dfarm, dwood, apast, agrass	501.6195	1.3307	0.2024
dgrass, dwood, apast, agrass	501.6321	1.3433	0.2012

($SE(\hat{\beta}_{agrass}) = 0.000005$). Using the average parameter estimates in the original best-fit model, the best fit model for deer activity was $Y_{deer} = 0.7439 - 0.5138(\text{dwood}) - 0.0241(\text{apast}) + 0.011(\text{agrass})$.

When only sample units along the edges of blocks of grassland were considered, the most important variable influencing white-tailed deer activity was the number of wetlands. The variable importance indices of the distance to farmstead, distance to woodland and area of grassland also indicated they may influence deer activity (Fig. 6). When only the sample units located along the edge of blocks of grassland were considered, the goodness-of-fit statistics for the global model (Pearson $\chi^2 = 705.85$, df = 697, $P = 0.3998$) indicated a good fit to the data and no evidence of overdispersion ($\hat{c} = 1.01$). There was only one best-fit block edge ($\Delta AIC_C < 2$) model. The parameter estimates and their standard errors for the

$Pr(deer) = 1 / 1 + e^{0.7726 + 0.4848(dfarm) - 0.3205(dwood) - 0.0306(awood) - 0.0173(apast) - 0.1446(nwet)}$

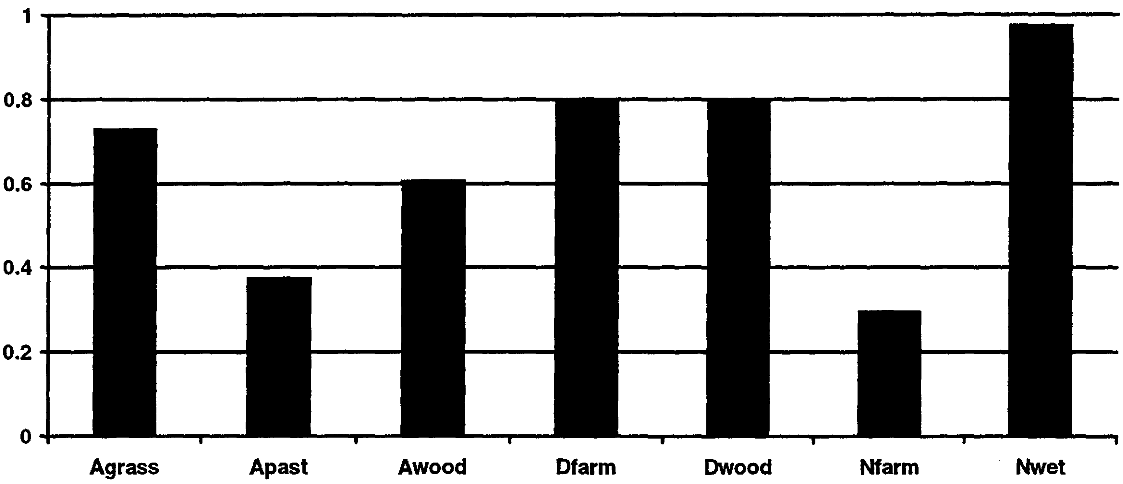


Figure 6. Relative importance of landscape variables and the best-fit model for predicting deer activity on block edge sample units.

included variables were: $\hat{\beta}_{dfarm} = 0.4848$ ($SE(\hat{\beta}_{dfarm}) = 0.2833$), $\hat{\beta}_{dwood} = -0.3205$ ($SE(\hat{\beta}_{dwood}) = 0.1392$), $\hat{\beta}_{awood} = -0.0306$ ($SE(\hat{\beta}_{awood}) = 0.0183$), $\hat{\beta}_{agrass} = -0.0173$ ($SE(\hat{\beta}_{agrass}) = 0.0101$) and $\hat{\beta}_{nwet} = -0.1446$ ($SE(\hat{\beta}_{nwet}) = 0.063$). The best-fit model was $Y_{deer} = 0.7726 + 0.4848(dfarm) - 0.3205(dwood) - 0.0306(awood) - 0.0173(agrass) - 0.1446(nwet)$.

<u>Direction of Movements</u>

White-tailed deer movements perpendicular to the grassland - row cropland edge differed significantly among sample unit types ($\chi^2 = 219.62$, df = 4, $P < 0.001$). Less than 20% of deer movement direction along straight edges (road ditch, drainage ditch, sides of blocks of grassland) was perpendicular (into or out of grass habitat) to the grassland - row cropland interface, whereas along convex and

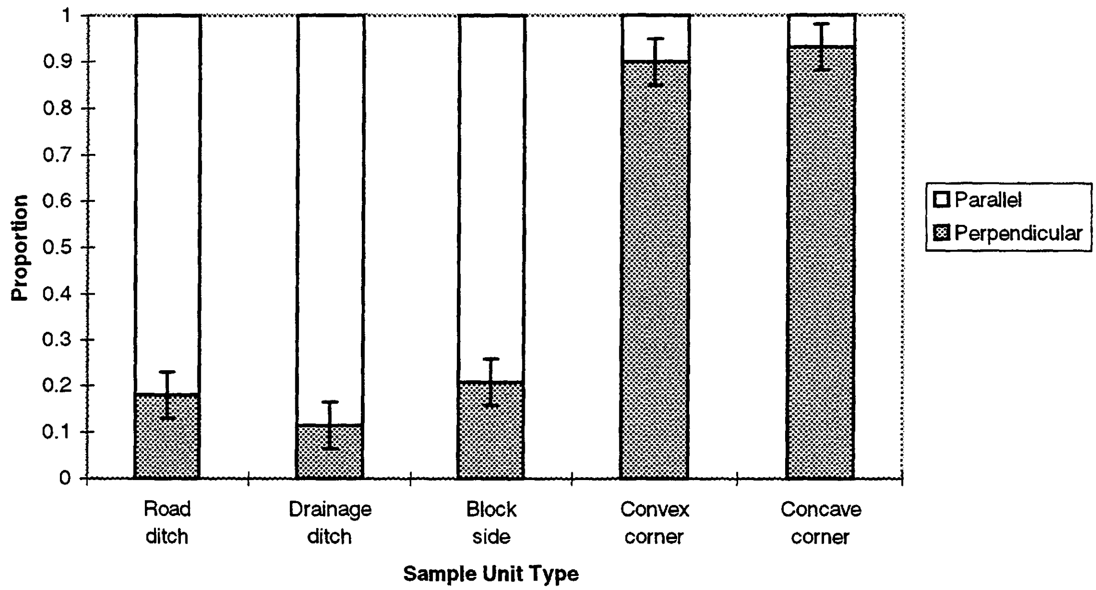


Figure 7. Relative proportion of deer movement perpendicular (into or out of grassland) and parallel to the grassland - row cropland interface.

concave edges greater than 90% of movements were perpendicular to the grassland - row cropland interface (Fig. 7).

Discussion

On isolated sample units, the positive influence of the amount of grassland habitat and negative influence of distance to grassland habitat both support previous studies that found grassland was used by deer (Gould and Jenkins 1993, Beier and McCullough 1990, Naugle et al. 1997). My results are also consistent with previous studies that found a strong negative relationship with distance to woodland cover (Beier and McCullough 1990, Roseberry and Woolf 1997) supporting the idea that woodlands may be a center for home ranges of white-tailed deer (Vercauteren and Hygnstrom 1998). My finding on the negative influence of the area of pastureland (including hayland and alfalfa) is similar to a previous study (Selting and Irby 1997) that found a positive correlation between the distance to alfalfa and activity.

Similar relationships between deer activity and some landscape variables were found on sample units along the edge of blocks of grassland as were found on isolated sample units. The strong negative relationship of distance to woodland to deer activity supports findings from previous studies (Beier and McCullough 1990, Roseberry and Woolf 1997), however; there was a weak negative influence of area of woodland on deer activity which is not supported by other studies. White-tailed deer appeared to avoid farmsteads, which may be a response to human disturbances. Another interesting finding of this study was a negative relationship to the number of wetlands. Others have found that deer use emergent wetland vegetation as bedding areas. Deer activity seemed to be negatively related to some landscape composition variables that previously were found to be a preferred deer habitat. My results may be a result of deer selecting these preferred habitats and spending less time along the edges of grassland blocks where my sample units were allocated.

My findings on direction of movements support ideas about the importance of corners as funnels (Ims 1995) of activity into or out of a patch of habitat. Strip habitat, such as fence lines, road ditches and drainage ditches, appeared to be more important for traveling between areas of higher activity.

Management Considerations

My analyses address the landscape use of white-tailed deer in northern Iowa, the Midwest and the Great Plains. Once habitat is lost, the configuration and management of the remaining patches in agricultural landscapes becomes important for the conservation and management of deer and other wildlife species. Understanding how deer use different landscape configurations could help managers choose among land use policies that would reduce the impact of deer on cropland and vehicle damage. In certain areas where deer and traffic populations are both high, manipulation of landscape configuration may reduce the risk of deer-vehicle accidents.

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CHAPTER 4: GENERAL CONCLUSIONS

This study was designed to determine where and how predators use landscape features without affecting their movements. Others have used scent stations (Roughton and Sweeny 1982) or other approaches to assess activity and habitat use. There is an increased potential for bias on baited scent stations (Allen et al. 1996) which can attract predators from up to 100-m away depending on species (M. A. Sovada, Northern Prairie Wildlife Research Center, personal communication). Predators react differently to constructed track stations, designed to prevent the elements from damaging tracking plates, and may be attracted to, or avoid, the structure. This study was designed to determine where and how predators use landscape features without affecting their movements. My passive track stations, which were a modification of the technique used by Sargeant et al. (1993) and Sovada et al. (1995), were un-baited and designed not to disturb the habitat significantly so that true activity of predators would be recorded. The technique also worked very well for identifying deer activity and similar analyses were done on both sets of data.

Land use was characterized using remotely sensed aerial imagery and a Geographic Information System (GIS). Specific variables relating landscape composition and configuration to the activity of predators and deer were measured and quantified using GIS for inclusion into statistical models.

Traditional modeling approaches do not take into account model selection uncertainty (Burnham and Anderson 1998). I used Akaike weights (Burnham and

Anderson 1998) to quantify the importance of landscape composition and configuration variables as well as to account for uncertainty in model selection. Weights were used to determine the most influential landscape variables on the relative activity of a species.

By understanding the effect of landscape composition and configuration on predator movement and activity and activity, managers can use GIS to predict predator activity and risk on nesting ducks, pheasants or other ground-nesting grassland birds. Managers in Iowa and across the northern Great Plains could use these models when creating or manipulating the habitat and estimate beforehand the likely impacts of predator activity. Understanding the functional relationships could help in choosing policy alternatives. Similarly, with white-tailed deer, managers could identify areas with high crop damage or high occurrences of vehicle accidents and then manipulate the habitat in order to reduce detrimental effects.

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